Evaluation of Supercomputer Technology for Surface Coal Mining Geotechnical Modelling Applications

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Preface

This report is submitted in accordance with Milestone No. 8 of the DSS Contract No. 55SS.23440-7-9200. It is the final report on this project and deals with activities specified in the project plan of the above contract.

This project involves a study undertaken by the Advanced Computing Technology Centre (ACTC) at The University of Calgary on behalf of Coal Research Laboratories of the Canada Centre for Mineral and Energy Technology (referred to hereafter as CANMET), a branch of Energy, Mines and Resources Canada. This study was conducted at The University of Calgary (which owns and operates a supercomputer — the Cyber 205) and involves the Evaluation of Supercomputer Technology for Surface Coal Mining Geotechnical Modelling Applications.

Supervision of this project was carried out by Dr. B. Manas Das of CANMET/EMR, based in Coal Research Laboratories (Devon, Alberta). Mr. Dennis Nikols of the Alberta Research Council who provided liaison on behalf of Alberta Geological Survey, Mr. Andrew Hickinbotham of TransAlta Utilities of Alberta, and Dr. Neil Wade of Monenco Consultants and Mr. Peter Sheehan of Smoky River Coal, Ltd. on behalf of the mining industry.

The work discussed in this report was performed under the guidance of C. (Raman) Janakiraman P.Eng. (Principal Investigator) and by the staff members of Supercomputing Services (University of Calgary): Dr. Doug Phillips (Sr. Applications Analyst), Mr. Bryan Gooding (Programmer Analyst), and Mr. Prem Domingo (Programmer Analyst) . The graphics interface was done by Paul Mikulecky and Richard Bubric of ACTC; the report was edited by Ms. Vivian Hindbo and figures done by Mrs. Margo Elliott, both of ACTC

The work covered by this report consists of an evaluation of supercomputing technology to coal mining geotechnical modelling applications. The principal aim was to assess the need for software development for selected mining areas (like coal and oil sands) in partnership with the mining industry and government departments. This was done with a view to improving safety, productivity, and competitiveness of the mining sector.

This project was carried out under a contract from Canada Centre for Mineral and Energy Technology (CANMET), Federal department of Energy, Mines and Resources , which had a partial support from Federal Panel on Energy R & D (PERD).

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This project was made possible by the Government of Alberta's prepurchase of supercomputer time on the University of Calgary's Cyber 205; and support from two private firms — TransAlta Utilities of Alberta and Smoky River Coal, Ltd. (Grand Cache, Alberta) — both provided data for the study.

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Executive Summary

Introduction

An evaluation of supercomputer applications to geotechnical modelling applications was performed through a literature and software survey, contacts with those in the computer software industry that provide software to the mining industry, and a feasibility study of pit slope programs. The following is a summary of the key points of this investigation.

Much of the initial work was an educational process to exchange information about the supercomputer, its associated power for mathematical simulation and its possible application to problems in the mining industry. Central sources of information for this study were mining companies, research institutes and third party software developers.

Wherever possible, contacts were made with companies, research scientists, and consultants in the U.S.A., U.K., W.Germany and Japan to provide an international perspective to supercomputer use in mining. Preliminary indications were that expertise is available in numerical modelling and that the experts are willing to collaborate in joint projects and share technology for mutual benefit. An example is the case of the U.S.B.M., Pittsburgh Research Centre, which has applied mathematical techniques to spontaneous combustion modelling of coal.

The Pit Slope Manual, pit slope programs and documentation were examined to determine what can be done for users. The work was subdivided into phases: literature survey, feasibility study, conversion planning and alternate modelling approach for vectorization.

Pit slope software packages studied include:

- Financial Analysis
- Stability Analysis
- Discodat (Structural Geology)
- Seepage (Groundwater Analysis)
- Rotational Shear
- Domain Analysis (Structural Analysis)

The purpose in this preliminary analysis was to collect software used for large scale computation, currently available to CANMET/EMR. The benchmark problems were assessed (using the applicable utilities and tools available on

the supercomputer) and a first run scalar version of the software on the Cyber 205 supercomputer was put together.

Report Highlights

Clearly, the potential use of supercomputer technology applied to problems unique to the Canadian mining situation will require a collaborative effort among industry, academia and government. Merely providing engineers access to supercomputing power does not in itself assure that they will become involved in more complex model development techniques. Potential users also need guidance to learn how to formulate their problems and to determine if supercomputing can offer solutions to these problems.

In response to this, available software which the mining industry can take advantage of for its immediate use were carefully examined. One way to address the issue of supercomputing software requirements and guide potential users is by means of case studies in the areas of interest. These case studies provide applications experience and insight into model development. A few carefully selected applications showed the entire model development process in considerable detail – from mathematical formulation to algorithm design, choice of appropriate software, and coding.

After carrying out a feasibility study of carefully selected benchmark problems (and the associated documentation) the following issues were discussed:

- machine architecture
- efficiency of algorithms
- relevant software available in the public and private domains
- use of appropriate software optimized for the supercomputing environment
- present trends in vector and parallel processing
- solutions oriented computing opportunities for the mining industry
- potential application areas where complex problems exist which are not amenable to traditional mainframe solutions
- the role of CANMET/EMR in forming industry partnership with academia to promote the transfer of supercomputer use for the benefit of the mining industry in general, and surface mining geotechnical engineering in particular

The mining industry contacts indicated the following areas as most suitable for industry applications:

- engineering analysis – typically finite element studies
- large scale simulation and mathematical programming
- general research – such as for environmental modelling
- graphics

Discussion with the mining industry revealed that the most suitable areas for further study would be the following:

- geotechnical engineering (deformation and progressive failure of open pit slopes including slope design and stability of dumps)
- geophysical applications (coal exploration)
- surface seismic applications (in-seam coal and rock characterization)
- mine planning (large scale simulation studies)
- material handling (simulation and mathematical modelling of mining and processing operations)
- environmental planning (reclamation studies and disposal of hazardous waste material)
- spontaneous combustion of coal (numerical modelling techniques applied to combustion processes)
- *in situ* mine modelling (underground tunnel facility for oil sands)

Long term development will certainly involve geotechnical applications of remote sensing, sensors, geosensing, microseismic techniques and mine automation using intelligent mining systems such as robotics.

The following factors will play a major role in the development of supercomputer applications to mining:

- productivity enhancements to improve competitiveness
- ability to absorb advanced technology
- complexity of mining
- forecasting of market share and demand for Canadian coal
- mining industry support of industrial partnership with university research centres in advanced R & D programs
- research into technology related to mining safety
- management techniques to lower cost of production
- further research and development support work for the solution of new problems which perhaps have never before been addressed by mainframe computers

Currently it is difficult to map out an exact work program with delivery dates, products and inputs. Despite the discussions just completed with various organizations, there are many gaps in information on mining models suitable for application on supercomputers. Moreover, in the process of undertaking any work program that involves research areas where the path has not been well trodden by other analysts, there will inevitably be false starts and backtracking. In view of the size of the task and the limited time available, it was necessary to tackle small pieces of the overall problem one at

a time in a realistic and selective fashion, taking into account the areas where the need is greatest.

The following recommendations are based on analysis of the information gathered from industry, universities, research centres and government contacts in Canada and the United States. The conclusions are based on the information obtained during this investigation. Further refinements and modifications will result from reactions to the report from potential participants in any future industry partnership.

- Surface coal mining modelling on supercomputers is a vast area still very much in a state of infancy in terms of both software and graphics requirements. One should, therefore, be realistic in his/her expectations about what can be achieved with the available limited resources (even pooled resources) or in a relatively short time span.

- The gaps in information and understanding of large-scale computational requirements of the mining industry need to be filled. This would involve the coordination and analysis of the research results of others (including information from abroad), providing a basis for future supercomputer modelling work.

- Several critical areas for supercomputer applications have been identified as:
  - geophysical studies,
  - geological and mathematical modelling studies,
  - geotechnical studies, geomechanical studies,
  - material handling, automation studies, and *in situ* mining and environmental studies.

- It has become clear that the first priority item should be the development of a reasonable slope stability model for the surface coal mining industry. With the cooperation of TransAlta Utilities, Smoky River Coal Ltd. and CANMET/EMR, it should be possible to develop a model as an adjunct to the existing pit slope program if this is done in a supercomputer environment.

- The implications of the feasibility study directly suggest the need for the following:
  - user applications need to be converted to take full advantage of the processing power of the central processor,
  - utilities which provide file management, database, and input-output capabilities require further improvement,
  - high speed input/output is critical for applications development on a supercomputer system,

- high-speed network access is also important for remote users, and
- high performance graphics and workstations will allow users to have the power to manipulate and display the large volumes of data that the supercomputer is capable of generating and returning to the user.

The most productive way of developing a reasonable slope stability model for surface coal mining appears to be to adopt and adapt existing operational modelling structures. There are a number of alternative models or programs to work with, including

- the existing EMR Pit Slope program(s),
- the U.S. and Australian geotechnical models,
- available surface coal mining programs developed by Canadian sources,
- computer models available from hardware/software vendors, and
- new models developed from scratch, drawing on the best features of existing models.

Resurrecting, strengthening and updating the EMR pit slope or other surface coal mining models seem like the least expensive alternative to pursue. Where there are weaknesses, particularly for a supercomputer system, other pieces of methodology could be incorporated from other models.

If the cost is reasonable, documentation and machine readable code should be obtained from numerical models developed at Mining Research Laboratories (CANMET/EMR) in Ottawa or from the U.S. Bureau of Mines for their 2-D and 3-D models. A similar attempt should be made to acquire pre- and post-processing geotechnical application code available from sources listed in the software directory.

Finally, further research is required for the SPRD method (Stress, Property, Rheology and Deformation method) developed by Serata Geomechanics for future use in a supercomputer environment. Geotechnical modelling applications (using sophisticated computer models) for underground test facilities in oil sands mining should be investigated as well.

Sommaire du comité d'étude

Introduction

Une évaluation des applications sur super-ordinateur se rapportant à la modélisation géotechnique a été effectuée en étudiant documentations et logiciels, en s'entretenant avec des informaticiens qui procurent des logiciels aux industries minières, et en menant une étude sur la viabilité d'un logiciel d'étude d'une mine à ciel ouvert. Voici le sommaire des points importants de cette enquête:

Le travail préliminaire consistait surtout en un procédé éducatif dans le but d'échanger l'information sur le super-ordinateur quant à sa capacité pour la simulation mathématique et son application éventuelle par rapport aux problèmes spécifiques à l'industrie minière. Les sources principales d'information de cette étude proviennent de compagnies minières, d'instituts de recherche et de développement, et de réalisateurs de logiciels de tierce source.

Dans la mesure du possible, nous avons contacté des compagnies, des maîtres de recherche scientifique et des experts des Etats-Unis, de la Grande-Bretagne, de l'Allemagne de l'Ouest et du Japon. Ces contacts ont fourni une perspective internationale sur l'usage du super-ordinateur dans l'industrie minière. Il en est ressorti l'idée première que l'expertise en modélisation numérique devienne plus accessible et que les experts soient en mesure de collaborer dans des co-projets et de prendre mutuellement avantage de cette nouvelle technologie. Le cas de U.S.B.M. du Pittsburgh Research Center, qui a appliqué des techniques mathématiques pour simuler la combustion spontanée du charbon en est un exemple.

Le manuel, la documentation et le logiciel d'étude sur les puits à ciel ouvert ont été examinés afin de déterminer comment nous pourrions aider leurs utilisateurs. Ce travail a été réparti en plusieurs secteurs.

L'ensemble d'étude du logiciel comprenait:

- Analyse financière
- Analyse de la stabilité
- Discodat (Géologie structurale)
- Ruissellement (Analyse des eaux souterraines)
- Cisaillement rotatoire
- Etude de l'environnement (Analyse structurale)

Le but de cette analyse préliminaire était de regrouper les logiciels utilisés présentement dans les calculs de grande échelle et disponibles chez CANMET/EMR. On a procédé à une évaluation des performances (en utilisant les programmes utilitaires disponibles sur le super-ordinateur) et on a établi un premier essai d'envergure de la version du logiciel sur le super-ordinateur Cyber 205.

Caractéristiques du rapport

Il est évident que l'application éventuelle de la technologie du super-ordinateur aux problèmes de l'industrie minière au Canada exigera un effort de collaboration entre l'industrie, les milieux académiques et les gouvernements. Le seul fait d'offrir aux ingénieurs l'accès au super-ordinateur ne garantit pas qu'ils aillent s'impliquer dans le développement des techniques de modélisation encore plus complexes. Les utilisateurs éventuels devront être guidés afin d'apprendre comment formuler leurs problèmes et de déterminer si le super-ordinateur peut offrir des solutions à ces problèmes.

Néanmoins, on a soigneusement examiné les logiciels que l'industrie minière pourrait utiliser dans l'immédiat. Une façon de percevoir la nécessité d'obtenir des logiciels élaborés et de conseiller leurs utilisateurs, serait d'étudier spécifiquement des problèmes particuliers. De telles études fourniraient des applications concrètes et une compréhension plus approfondie du développement de modèles. Il suffirait de quelques applications bien choisies pour démontrer l'ensemble du processus de développement de modèles jusqu'aux détails caractéristiques - des formules mathématiques jusqu'au concept algorithmique, au choix du logiciel et à la codification.

Après avoir répertorié toutes les caractéristiques et les problèmes notoires (ainsi que la documentation qui s'y rapporte) en menant cette étude préliminaire, les sujets suivants ont été traités.

- architecture de la machinerie
- efficacité des algorithmes
- disponibilité de logiciels dans les secteurs privés et publiques
- l'usage de logiciels spécifiquement reconnus pour l'étude de l'environnement sur super-ordinateur
- tendances actuelles dans le domaine du traitement vectoriel et parallèle
- l'emploi d'ordinateurs pour trouver les solutions aux problèmes relatifs à l'industrie minière
- sphères d'applications où certains problèmes difficiles ne sont pas soumis à des solutions traditionnelles
- le rôle de CANMET/EMR pour établir une coopération entre l'industrie et le milieu académique afin de promouvoir l'utilisation du super-ordinateur dans l'intérêt de l'industrie minière en général et de la géotechnique de l'exploitation à ciel ouvert en particulier

Les contacts avec l'industrie minière ont montré que les applications industrielles suivantes avaient suscité un certain intérêt:

- analyse de l'ingénierie - étude typique d'éléments finis
- simulation à grande échelle et programmation mathématique
- recherche générale - telle que celle utilisée pour la modélisation environnementale
- représentation graphique

Des pourparlers avec l'industrie minière ont révélé la nécessité d'intensifier les études dans les secteurs suivants:

- applications géophysiques (exploitation du charbon)
- applications sismiques en surface (caractérisation des couches de roche et de charbon)
- ingénierie géotechnique (déformation et affaissement progressif des pentes des mines à ciel ouvert, y compris les voies d'accès et les remblais)
- planification des mines (études de simulation à grande échelle)
- manutention des matériaux (simulation mathématique et modélisation des exploitations minières et du procédé industriel)

- aménagement de l'environnement (études de restauration des lieux, et enlèvement des déchets toxiques)
- combustion spontanée du charbon (techniques de modélisation numérique appliquée au processus de la combustion)
- modélisation de mines in situ (installations de tunnels souterrains pour les sables bitumineux)

Le développement à long terme comprendra certainement des applications géotechniques de télédétection, d'étude de détecteurs, de géodétection, de techniques microsismiques et d'automatisation des mines en employant les systèmes de la robotique.

A notre avis, en ce qui concerne l'adaptation du super-ordinateur à l'industrie minière, les éléments suivants joueront un rôle:

- gain concurrentiel par accroissement de la productivité
- adaptation au progrès de la technologie
- multiplicité de l'industrie minière
- prévisions du marché du charbon canadien en fonction de l'offre et de la demande
- appui de l'industrie minière pour une coopération avec les groupes de recherche et de développement des milieux universitaires
- recherches techniques vis-à-vis de la sécurité minière
- techniques de gestion visant à réduire les coûts de production
- intensification de recherche et de développement visant à prévoir et résoudre de nouveaux problèmes qui n'ont peut-être encore jamais été soumis à l'analyse de l'ordinateur.

Actuellement, il est difficile de prévoir quand un logiciel serait disponible en précisant des dates, des produits et des valeurs. Malgré de nombreuses discussions avec diverses organisations, il y a encore de nombreuses lacunes concernant les données sur les modèles miniers que l'on soumet aux super-ordinateurs. De plus, lorsqu'on élabore un logiciel particulier qui touche des domaines de recherche encore jamais étudiés par d'autres analystes, il y a inévitablement des faux-départs et des impasses. Etant donné l'importance de l'étude du projet et le peu de temps disponible, il fut nécessaire d'aborder l'ensemble du problème par étapes, une à une, de façon réaliste et sélective, en tenant compte des secteurs où les besoins sont les plus importants.

Les recommandations suivantes sont basées sur l'analyse des informations accumulées par l'industrie, les universités, les centres de recherche et les départements gouvernementaux au Canada et aux Etats-Unis. Les conclusions sont fondées sur les informations recueillies pendant cette étude. Il est à prévoir de nouveaux détails et certaines modifications suggérés par d'éventuels participants devenant impliqué dans un projet industriel, lorsqu'ils prendront contact avec ce rapport.

- La modélisation de l'exploitation du charbon à ciel ouvert sur super-ordinateur demeure un vaste champ encore en voie de développement quant aux logiciels et aux graphiques. On se doit donc d'avoir une vision réaliste vis-à-vis de ce qui est possible d'accomplir avec le peu de matériel actuellement disponible (même en considérant tout le matériel convergeant de sources diverses) et dans un délai relativement court.

- Il faut remédier au manque d'information et de compréhension quant aux besoins du traitement par l'informatique des données numériques à grande échelle dans le secteur de l'industrie minière. Cela comprendrait la coordination et l'analyse des résultats de la recherche entreprise par d'autres (y compris les renseignements provenant de l'étranger), afin de fournir une base pour les futurs projets de modélisation par super-ordinateur.

- En ce qui concerne les applications sur le super-ordinateur, on a identifié certains secteurs critiques:

  - les études géophysiques,
  - les études de modélisation géologique et mathématique,
  - les études géotechniques, les études géomécaniques,
  - la manutention des matériaux, les études d'automatisation,
  - l'exploitation minière "in situ" et les études de l'impact sur l'environnement.

- On a reconnu que l'ordre de priorité était le développement d'un modèle visant la stabilisation des pentes dans l'exploitation du charbon à ciel ouvert. Avec la collaboration de Trans-Alta Utilities, Smoky River Coal Ltd et de CANMET/EMR, nous sommes confiants qu'il sera possible de développer un modèle auxiliaire à l'actuel logiciel d'étude de stabilisation des pentes des mines à ciel ouvert, si ceci s'effectue sur super-ordinateur.

- Les implications directes de cette étude ont abouti aux recommandations suivantes:

  - le logiciel de l'utilisateur a besoin d'être converti sur le système du processeur central de sorte à prendre pleinement avantage de sa puissance de traitement

  - les programmes utilitaires qui permettent l'organisation des fichiers, des bases de données, et les possibilités d'entrées et de sorties des données, a besoin d'être amélioré

- pour la mise au point de programmes sur le système du super-ordinateur, la rapidité d'exécution des entrées et des sorties des données est primordiale

- des terminaux de travail et une très grande résolution graphique devrait permettre aux utilisateurs de brasser et d'afficher de larges quantités de données lesquelles le super-ordinateur est capable de traiter et de renvoyer à l'utilisateur.

La façon la plus efficace pour développer un modèle d'étude de stabilisation des pentes pour l'exploitation du charbon à ciel ouvert, serait d'adopter les structures de modélisation déjà en place puis de les adapter. Il existe un bon nombre de modèles disponibles ou de programmes équivalents et parmi lesquels on y trouve les suivants:

- les programmes de talus de bassin minier de EMR,
- les modèles géotechniques des Etats-Unis et de l'Australie,
- divers programmes disponibles sur l'exploitation du charbon à ciel ouvert, développés par des sources canadiennes,
- certains modèles mis en vente sur le marché par certains distributeurs de logiciels, et
- des modèles entièrement nouveaux, développés d'après les meilleurs critères utilisés dans les modèles déjà existants.

Il semble que l'option la moins chère serait la réintégration, l'amélioration et la mise à jour de divers modèles tels ceux d'EMR conçus pour les talus de bassin minier ou encore, d'autres modèles utilisés pour l'exploitation du charbon à ciel ouvert. Là où l'on retrouve des lacunes, particulièrement en ce qui concerne le système du super-ordinateur, on pourrait introduire d'autres éléments méthodologiques à partir d'autres modèles.

Si le prix est abordable, on devrait se procurer la documentation et un logiciel sur disque des modèles numériques développés aux laboratoires de recherche minière (CANMET/EMR) à Ottawa, ou pour leurs modèles à 2-D et à 3-D au Bureau des mines des Etats-Unis. On peut encore acquérir un logiciel spécial de traitement de données géotechniques lequel est disponible dans le répertoire du logiciel.

Enfin, il faudrait entreprendre de plus amples recherches quant à la méthode "SPRD" (Stress, Property, Rheology, Deformation), mise à jour par Serata Geomechanics pour l'utilisation future dans un environnement de super-ordinateurs. Il faudrait aussi étudier l'application de modélisation géotechnique (en se servant d'ordinateurs élaborés) pour les installations d'essais souterraines destinées à l'exploitation du sable bitumineux.

1.0 Introduction

After spending over three months discussing supercomputer analysis applied to mining, a project was initiated in December 1987. From the study it may be concluded that the field is enormously complex, burdened with a host of problems which are far from any satisfactory theoretical or practical solutions. Despite work done during the past five years (particularly in the U.S.A., Australia and West Germany), supercomputer modelling in geotechnical engineering is still in its infancy. The following report illustrates the difficulties and offers some practical suggestions of applying new technology to areas suitable to mining.

This report is divided into several sections. Section 2 provides the background including discussions of the value of Canada's coal exports, the overall scope of the project, and the initial literature survey and the compiled directory of computer programs. Section 3 focuses on current supercomputing technology and Section 4 on the theoretical foundations of surface mine geotechnical modelling applications. Section 5 discusses software applications to the mining industry including the desirability of software features. Supercomputer performance and software issues are described in Section 6. Section 7 deals with surface coal mining geotechnical modelling applications, and Section 8 discusses alternative modelling approaches based on this study. Section 9 is the Case Study Report that summarizes the evaluation done of surface coal mining software. Section 10 provides conclusions to the report. The case study report, a list of contacts/discussions held, a software application directory questionnaire, a glossary of terms, the bibliography, a schematic design for a Network of Research Centres[1], and a mining applications software directory.

2.0 Background

Mining technology has evolved slowly over the years. This is a result of a number of factors. Long-standing technical problems are complex, incompletely understood, and usually not amenable to laboratory experimentation. Both physical and financial risks are proportionately large, while the market for new technology is quite small. The most notable feature of progress to date is that virtually every advance has been made one element at a time, with each element compatible with the elements of an existing system that remains unchanged. Often, some new development in mining is the result of contributions from other branches of science and engineering.

Through most of the evolution of mining technology, mine planners found themselves dealing with technical decisions beyond the state of available technological knowledge or experience. They have been compelled to take risks and to extrapolate technical practices to meet the operating demands of the mine. In the early days, few analytical tools existed to bridge the gap between the established practices and demands; trial and error was one of the practical ways of overcoming the gap. This process matured into a development testing program in which new concepts were tried and modified until they worked. Although this procedure was reasonably successful, it became increasingly apparent that the iteration process between adoption and productivity gains was becoming prohibitively costly and time-consuming, and sometimes not very effective.

In conjunction with field development, increased fundamental research provided a foundation of information or data for improved design, correlation and analysis. This research encompassed a broad spectrum of disciplines including rock mechanics, mine ventilation, material handling, safety, and automation in hazardous environments. Industry, universities, and government laboratories became joint participants in this research endeavor. Quick adoption and transfer of current and future advanced technology is required to keep pace with the international competition.

An interesting illustration of the state-of-the-art technology is represented by the definite movement toward reliance on computational methods to establish mine design, with previous generation computers giving way to a new computational tool — the supercomputer. The term "supercomputer" is applied to a class of the most powerful large-scale computers available at any particular time. The cost/performance ratio of all classes of computers (from the largest to the smallest) continues to decrease rapidly, and today's desk-top computer has the power that years ago was available only in mainframes. Speed is gained both by improving logical design of the computer and by making electronic components of the machine faster. Hence, each generation of supercomputers has tested many new design ideas and component technologies that were later introduced in smaller, less expensive machines.

John S. Mayo of Bell Labs has defined "new domain" technology as a new technology that does something that was not only impossible, but truly inconceivable before it existed. The supercomputer has many new domains such as aerospace and automobile design, and molecular chemistry. The advent of the supercomputer with its associated power for mathematical simulation has brought a powerful new tool to the hands of the researchers.

The market for supercomputers has been rather small with the vast majority of machines being installed in research laboratories. However, since the early 1980s, the market has been growing with several hundred machines currently installed worldwide; the supercomputer age in industry is gradually emerging. To date, the supercomputers has led to a deeper understanding of such fields as fluid mechanics, quantum chemistry, astrophysics, structural engineering and genetics. Increasing numbers of scientific users are gaining access to supercomputing power. This will influence the use of fundamental research information for applications to mine design, resulting in innovative design concepts, improved certainty of predictions, automation in the mining environment, and minimization of costly mine planning and design changes. The overall effect will be improved safety and productivity.

Managing Canada's mining industry for effective operation and strategic advantage will require the generation of innovative ideas, new attitudes and quick adoption and transfer of current and future advanced technology. Yet, like other troubled basic industries, the mining industry has found it difficult to support necessary long-term research.

2.1 Coal Production in Canada

Historically, coal has played an important role in Canada's energy reserves. Coal production in Canada and Alberta reached record levels in 1986, and despite an apparent slow down in the industry, the latest statistics indicate that the volume of Canadian coal production in 1987 (Figure 1[2] and Figure 2[3]) was up a couple of percentage points from 1986 – standing at 57 million tonnes. Of the 25 million tonnes produced in Alberta in 1986, 17 million tonnes were used to generate electricity as shown in Table 1[4]. Despite less optimistic forecasts for the future growth of energy demands, significant increases in coal production and demand are forecast to 2010, especially for the generation of electricity. This illustrates the supply and demand for Alberta coal.

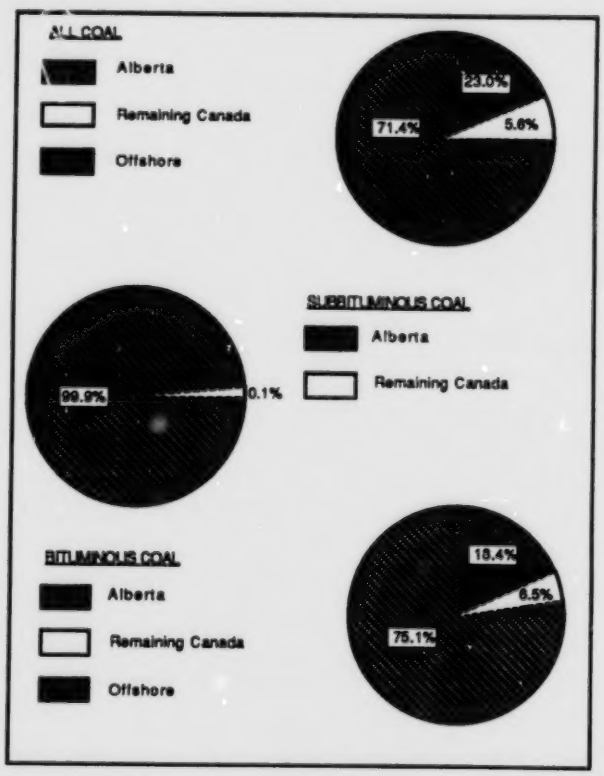


Figure 1 1986 Coal Deliveries

Table 1 1986 Coal Production (Tonnes)

		RAW	MARKETABLE
Subbituminous Coal		17,524,665	17,524,665
Bituminous Coal			
	Metallurgical	5,586,502	4,174,026
	Thermal	4,549,159	2,839,767
		10,135,661	7,013,793 (A)
Total		27,660,326	24,538,458

Note: (A) Includes 170,167 tonnes of low heating value by-product coming from a metallurgical coal preparation plant used in Alberta for the generation of electricity.

Exports were estimated at slightly more than 26 million tonnes compared to 25.9 million tonnes the previous year. Coal ranks as one of Canada's most valuable mineral export commodities, with annual exports valued at nearly $1 billion.

Although the present use of coal is mainly confined to power generation and coking for metallurgical purposes, technological developments may allow coal to be adapted to many applications, directly or through conversion to synthetic fuels.

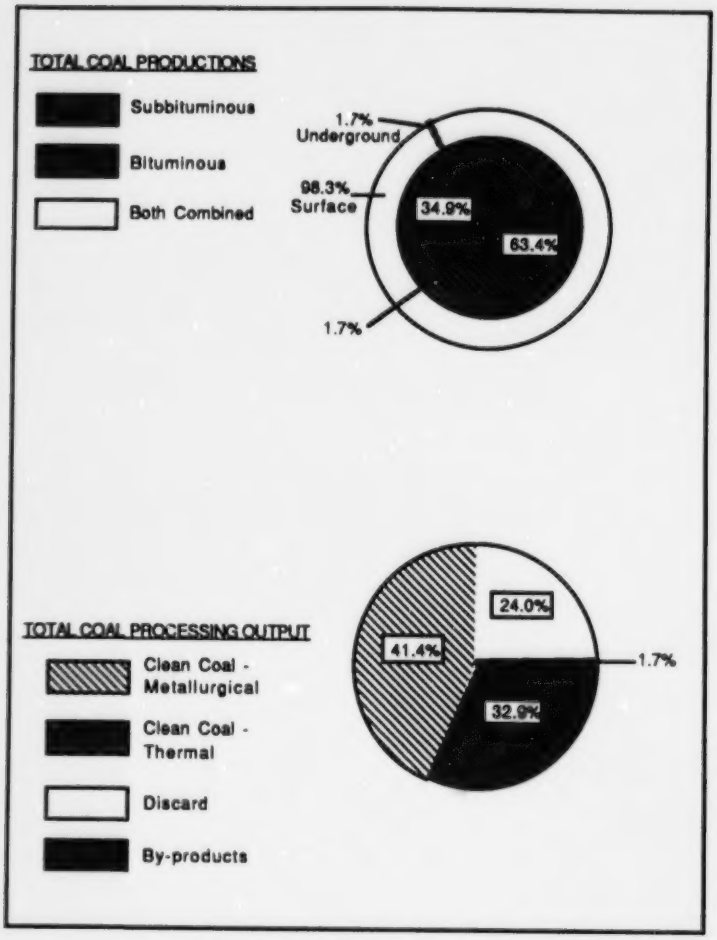


Figure 2 1986 Coal Production

Figure 3 [5]

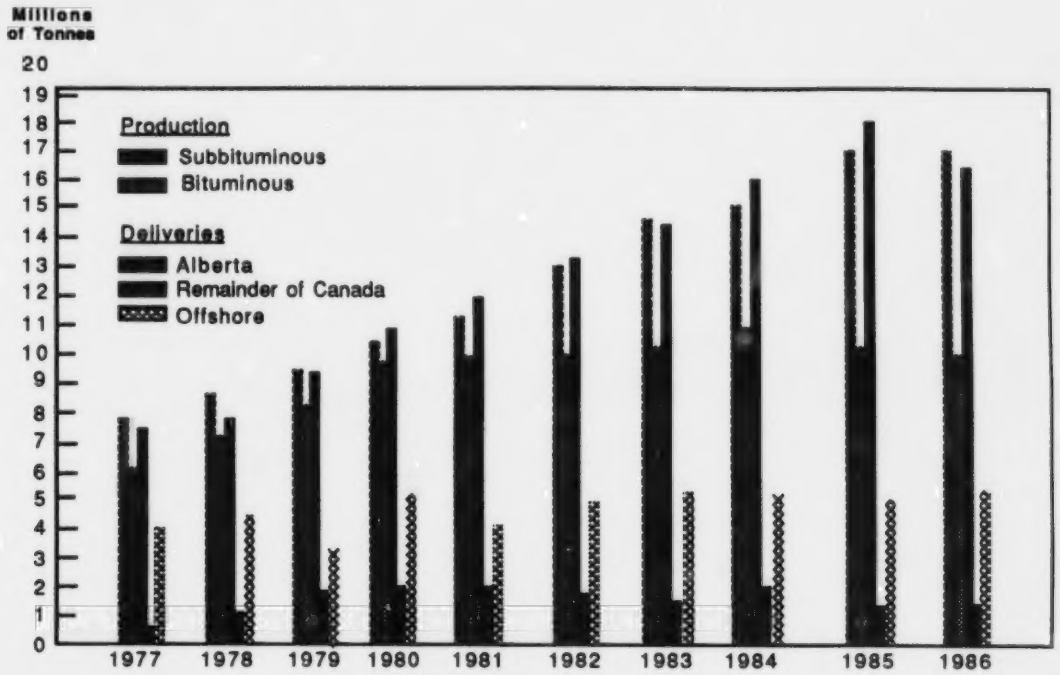


Figure 3 Coal Production and Deliveries

2.2 Project Scope

The objective of this project is to investigate large-scale computing tools which will make significant contributions to the advancement of mining technology. Particular emphasis is placed on computational methods which can benefit from a supercomputer such as the Cyber 205. The technical areas discussed in this study are engineering analysis, simulation and graphics. More specifically, the target of this study was the development of vectorized software which takes the following into account: state-of-the art in algorithm development, deficiencies in existing methodology, and potential application areas. This is described in detail using the pit slope program for geotechnical modelling applications in the case study section of the report.

This report evaluates the mining industry's current status and level of interest in supercomputer based applications. With this picture of the current situation, the future direction of vector and parallel processing as applied to advanced mining technology for the 1980s and beyond was investigated.

This project was partly intended to make recommendations and suggestions with respect to the possible role for EMR/CANMET in innovations of mining technology. Federal government interest in large-scale-computing devices is based on many concerns:

- the ability of EMR/CANMET to fulfill their mission requirements in national energy technologies
- the viability of the Canadian mining industries, particularly in light of increasing foreign competition
- the research and development that is performed in hopes of improving software development and the use of supercomputer
- the problem solving opportunities provided by supercomputers to members of the mining industry to perform innovations in mining technology

Project Phases

Evaluation of Supercomputer Technology for Surface Coal Mining Geotechnical Modelling Applications began in November 1987. The project was divided into three distinct phases:

1) Literature survey and software acquisition;
2) Preparation of a directory of mining software; and
3) Feasibility study using pit slope programs for benchmarking on the supercomputer (Cyber 205).

In order to meet the objectives of this project, a number of alternatives were also examined in detail to relate supercomputing technology applications to mining problems. This included items such as software adaptation and conversion to vector computers, pre- and post-processing design for interactive use, and flexible graphics output to examine the volume of output which the supercomputer is capable of generating.

2.3 Initial Information Survey

The primary sources of data for this project were literature reviews and telephone interviews with contacts in the mining and software industries. Telephone interviews were primarily with software developers, geologists, mining engineers and other agencies in Canada, although contact was also made with others in the United States and Australia. During the course of the survey, major coal mining companies in Canada were contacted and personnel interviewed.

There was no attempt made to summarize the results of the discussions held with various individuals on surface coal mine geotechnical modelling applications. A list of the individuals with whom discussions were held is attached in the Appendix and in most cases additional particulars are included.

Secondary sources included government statistics, various software reports, and application directories.

The initial research consisted of four major tasks:

1. Searching and documentation of pertinent information using the following publications:

   (a) I.B.M. Software Applications Directory
   (b) Control Data Corporation Applications Directory
   (c) Digital Equipment Applications Directory
   (d) ETA Systems Applications Directory
   (e) Cray Research Applications Directory (Boeing Computer Services)
   (f) U.S.B.M. Publications
   (g) Engineering Index
   (h) CISTI (N.R.C.) library search based on key word index

2. Developing a list of most likely computer users and software developers.

3. Developing a set of contacts with the private industry and universities to gain personal knowledge of industrial computer usage.

4. Investigating government documents in Canada, U.S.A., U.K., Australia and Japan which may contain or have reference to programs.

References to public documents and technical papers were acquired through universities, governmental and professional organizations, and other special institutions. The private sources from whom references were acquired (by either direct or indirect contacts) included mining and equipment companies, consulting firms, computer companies and other companies with a special interest in coal mining.

An interesting illustration of the state-of-the-art technology in mining is represented by activities such as seminars and conferences. Naturally, given all the work that has gone on in this field, an extensive set of papers and documents have been produced by a wide variety of authors. While a number of these documents have been collected in the course of the recent discussions and literature survey, no attempts have been made to compile a bibliography of relevant surface mine geotechnical modelling literature.

2.4 Directory of Computer Programs

A significant part of mining technology development involves computer applications: lately there has been widespread growth in operations, consulting, and research applications. Computer programs have grown in both complexity and size in all industries, so, to meet the current demand, extensive developments in hardware and software are sought. Along with rapid development, operating and research personnel were faced with many questions that have since been effectively analyzed by existing computer programs. The application of a number of these programs has become standard practice for managers and engineers.

The questions facing many potential and long-term users are: Who have developed particular programs and how have they applied these program to meet their specific needs? Also, how efficient are these people in making use of today's computing technology? In answer to these questions, an up-to-date directory of computer programs applicable to the Canadian coal mining industry is included. This directory of the surface coal mining models is attached to the end of this report.

Specifically, the directory is a listing of computer applications related to the quantitative modelling of surface coal and oil sands mining. The main intent of creating this directory was twofold: (1) it was an effort to unify the search for mining related computer programs for the benefit of individuals and organizations involved in the mining industry, and (2) it was compiled to identify the specific requirements of future use of supercomputer applications.

The directory primarily focuses on computer programs used in Canada, yet a number of programs developed and being used in foreign countries are also included. The computer applications in Canada today are numerous, therefore this directory is not intended to represent a complete listing of computer programs. Even though the directory is not exhaustive, it should serve as an initial reference that will aid individuals and organizations in finding further information concerning a particular program or application for use on supercomputers like the Cyber 205.

In order to locate a given program model, it is necessary to know the relevant application. The directory divides the programs into the following classifications: Geology and Geophysics, Structural Analysis (Geomechanical and Geotechnical), Material Handling, CAD/CAM/CAE, Graphic/Image Processing, and Environmental Engineering.

For each program, the directory lists the program name, a brief description, developer or contact, and additional computer software required to run the particular program. This list is based on the available information and additional particulars are available from the authors. Definitions of terms used in the table (and in this report in general) are contained in the Glossary.

A questionnaire was prepared to circulate to industry and other organizations in order to gather information on software currently in use. This was done with the intent to identify future mining applications on the supercomputer. A sample of this questionnaire can be found in the Appendix.

3.0 Supercomputers

Since the 1950s most large computers have shared an architecture named after John von Neumann, a prominent mathematician who played a major role in the invention and development of the digital computer. In the von Neumann architecture, data and program instructions both reside in memory, and instructions are sequentially interpreted and executed one at a time by the "processor". Traditional computers use this method of computation labelled "scalar processing".

Many of the supercomputers now popular, such as the Cray and the Cyber 205, are still based on a variation of the von Neumann design called "vector" processing. Vector machines gain their speed by breaking up computational tasks (such as addition and multiplication) into separate "pipelines" which allows certain problems to be executed far faster than if they had been done on mainframes. Figure 4[6] shows the current and projected supercomputers, 1960-90 based on the expected range of performance.

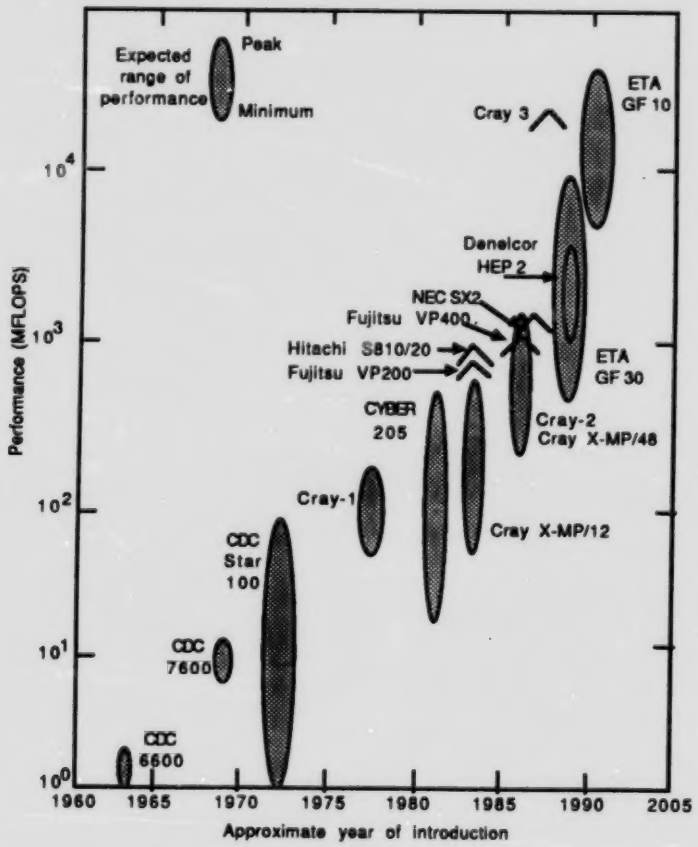


Figure 4 Current and Projected Supercomputers, 1960-90

Most computer scientists have concluded that the sequential von Neumann design can no longer sustain the rapid growth to which users have become accustomed (though component speeds will continue to improve). They are looking elsewhere for new design ideas, and their interest has turned to parallelism. In a parallel machine, rather than one processor working sequentially on the steps of solving a problem, many processors work simultaneously on the computation.

3.1 Review of the Cyber 205 Hardware

Before discussing some of the distinctions between scalar and vector processing and how they are relevant to peek performance on the Cyber 205, a simplified representation of the Cyber 205 hardware will be considered. Below is a list of the individual features of the system to which reference will be made:

- 400 million operations per second (400 MFLOPS[7])
- 2 vector pipeline processor (max 4)
- 4 million Word Central memory (32 million bytes)
- 10,000 million byte Virtual Memory (max 2 Trillion)
- Front end: Cyber 860, VAX 11/780
- Suitable for Scientific, Engineering and Technical Applications

Figure 5[8] shows the basic structure of the Cyber 205 at The University of Calgary. As can be seen there are a number of components to the machine, including a scalar processor, a vector processor (itself consisting of several sections) and 4 megawords of main memory which the processors share. There are also 8 input/output channels for communication with the rest of the hardware environment, including disk drives and front-end computers.

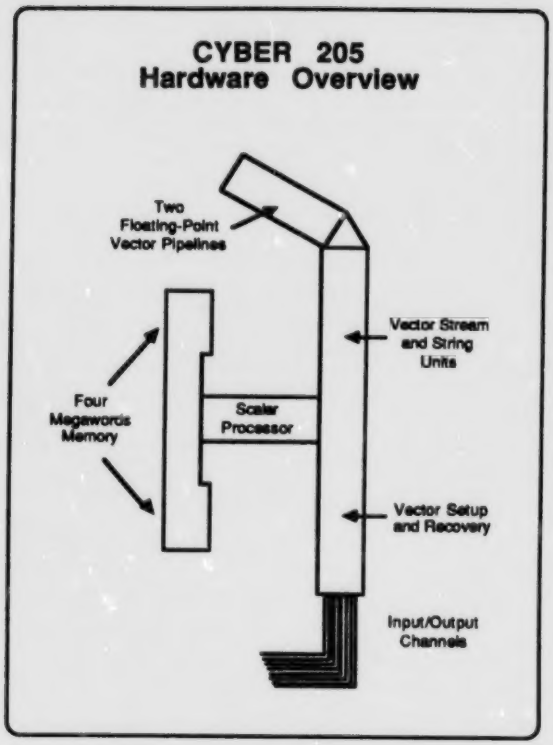


Figure 5 Basic structure of the Cyber 205 at The University of Calgary

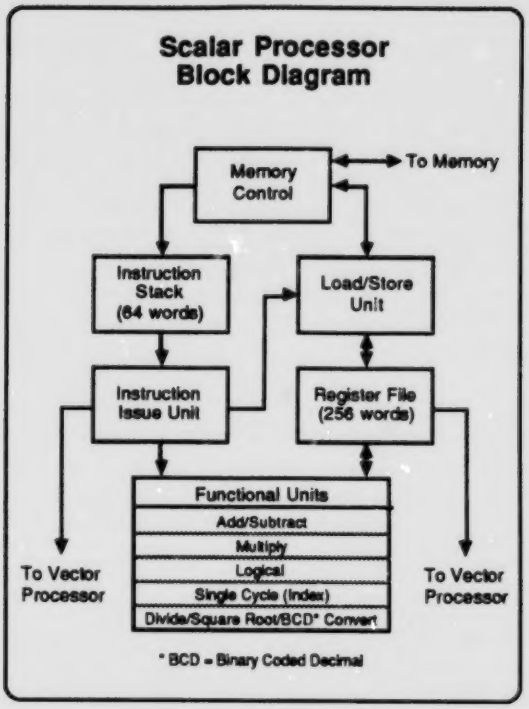


Figure 6 Scalar processor block diagram

Figure 6[9] is a block diagram of the scalar processor of the Cyber 205. Instructions to be executed are moved from a 64-word instruction stack and then on to the instruction issue unit where they are decoded. The instruction is then passed on to the vector processor or to one of the other units in the scalar processor for execution. Other basic components of the scalar processor include a 256-word register file, a load/store unit which looks after transfers of data to and from the registers, and a collection of hardware known collectively as the functional units. The functions performed by the functional units include basic arithmetic and logical operations on values obtained from the register file. In certain cases the output from one functional unit can be fed directly to the input of another; this process is called shortstopping.

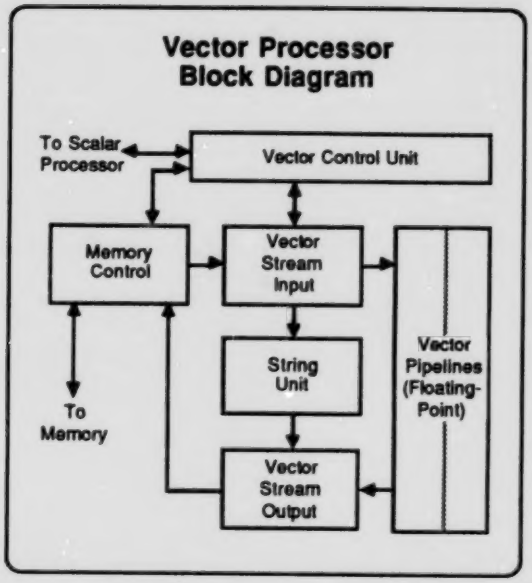


Figure 7 Vector processor block diagram

Figure 7[10] is a representation of the Cyber 205 vector processor. The vector processor acts on streams of data called vectors. The individual data values are referred to as elements of a vector. The total number of elements in a vector is called its length. Once the vector processor receives an instruction, the vector control unit takes over. The vectors that are manipulated in the vector processor are obtained from memory rather than registers (although the register file in the scalar processor may also be involved to store information that the vector processor needs to carry out its operation).

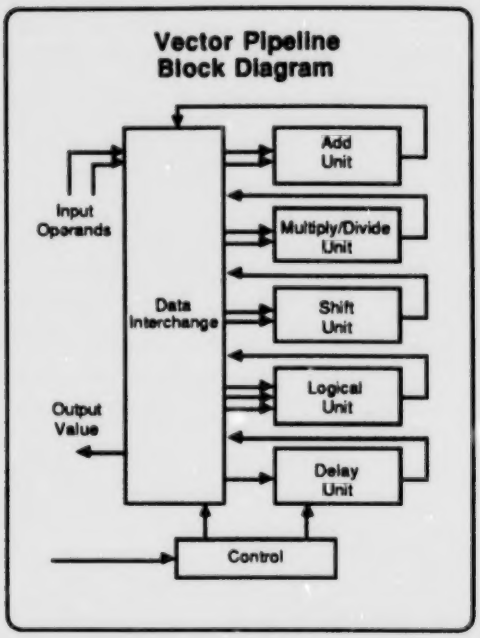


Figure 8 Vector floating-point pipeline block diagram

The vectors of data are fed through buffers located in the vector stream input unit before being sent on to a processor called the string unit (for bit string or character (8 bit) manipulation) or to units called the vector pipeline (for floating point operations on 64-bit words). As shown in Figure 8[11], each vector pipeline contains a full set of functional units similar to those found in the scalar processor. (The Cyber 205 at The University of Calgary contains two such pipelines.) As results are generated by the functional units, they are sent back to memory by way of buffers located in the vector stream output unit.

Having reviewed the basic components of the Cyber 205 hardware, the main purpose of this section will now be described, namely, to highlight the differences between the operations carried out by its scalar and vector processors.

3.2 Scalar Processing

Traditional computers use a method of computation called scalar or serial processing. In such machines there is a single stream of instructions which are interpreted and executed one at a time. Typically, each instruction operates on a single input value (such as when loading one number from memory to a register) or provides a single output value. Such machines can be characterized as being of a type called single instruction stream, single data stream type (SISD).

To provide a basis for comparison with vector processing (see Section 3.3), consider a simple FORTRAN DO loop to add together N=1000 elements from each of two arrays, A and B, to give a third array, C:

```
      PARAMETER  (N=1000)
      DIMENSION A(N),B(N),C(N)
      DO 10 I =1,N
      C(I) = A(I) + B(I)
   10 CONTINUE
```

An example of such a calculation, as processed by a typical scalar machine, is shown in Figure 9. In the lower right portion of the figure, a simplified instruction sequence is illustrated, such as might be generated in an assembly language listing of the compiled FORTRAN program. The sequence of operations begins with the loading of a single element of the array A and a single element of array B into a register. Next, the addition is performed and the result placed in a third register. Finally, the result is transferred to memory. Some testing is then done to determine if the end-of-loop index, I, has reached its upper limit, N. The whole process is repeated, until N=1000 pairs of A(I) and B(I) have been pairwise summed.

As illustrated in Figure 9[12], the process of adding the pairs of numbers requires that each instruction be completely finished before the following one can be started. In more modern architectures, various techniques have been used to increase the overall speed of computation by partially or completely overlapping the processing of successive instructions. The discussion thus turns to vector processing.

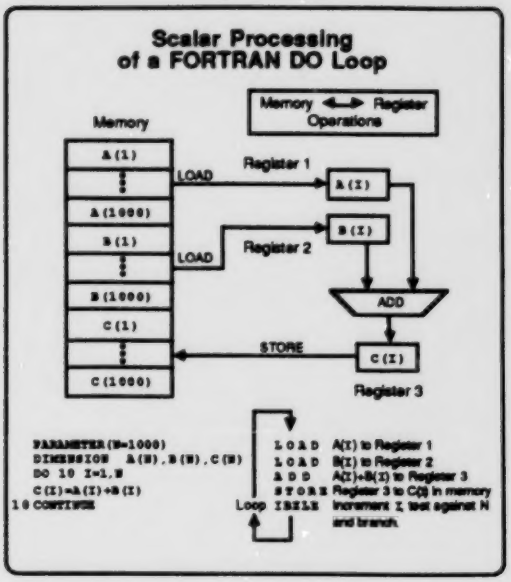


Figure 9 Scalar processing of a FORTRAN DO loop

3.3 Vector Processing

The need to increase execution speed has led to the development of another type of machine called a single instruction stream, multiple data stream computer (SIMD). Such machines can interpret special commands, called vector instructions, which result in the computer performing some operations on more than one input value. The same operation (for example, taking the negative of a value) is carried out for each element in the series of values making up an input vector. Vector processing simply refers to the capability of manipulating data in terms of vectors according to vector instructions. To see how the use of these vector instructions can lead to a considerable increase in the overall processing speed of a computer, reconsider the FORTRAN DO loop example of the preceding section.

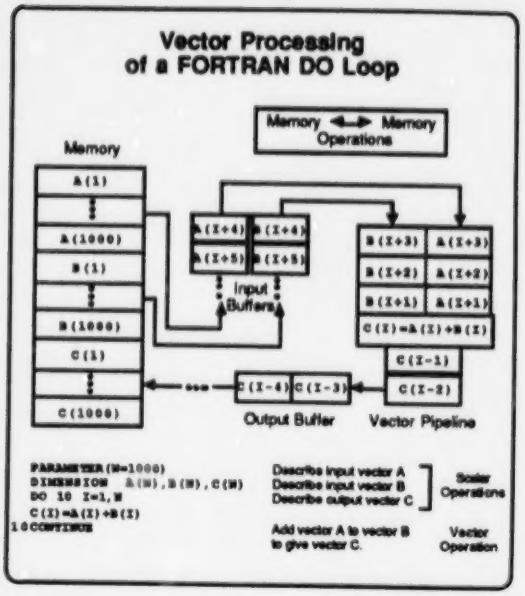


Figure 10 Vector processing of a FORTRAN DO loop

The vector processing treatment of this example is shown in Figure 10[13]. The overall flow of the data looks very similar to the scalar case pictured in Figure 9. However, the data values stream directly from memory to the add unit and back to memory, with temporary stops in input and output buffers rather than in registers. Also, the add unit in the vector case is embedded in a large piece of hardware called a vector floating-point pipeline. The main difference between the scalar and vector cases appears when one examines the type of instructions that the FORTRAN compiler produces, shown at the bottom right of each diagram. In the vector case, there are several scalar instructions needed to describe the addresses in memory of the input and output vectors and the number of elements in each vector (1000 in the example). Then there is a single vector instruction to do the 1000 additions. Note that the LOAD, STORE, and end-of-loop testing instructions that appear in each iteration of the loop in the scalar case are unnecessary in the vector case.

3.4 Pipelining and Segmentation

From what has been discussed so far, it is still not obvious that the use of vector instructions has produced any speed advantages. Conceptually, one must fetch the operands to be added and store the results back to memory in both the scalar and vector processing examples. What actually makes the vector processing cases much faster is that a significant portion of the Cyber 205 hardware is dedicated to the task of organizing the stream of data to the units where arithmetic is performed (vector pipelines) and back to memory. The key feature of this hardware, and the increase in processing speed that it permits, is that it allows two memory reads, some arithmetic, and a memory write to occur simultaneously.

Regarding Figure 10 as a snapshot at an instant in time, note that the result C(I) = A(I) + B(I) is about to be computed in the vector pipeline. A previously calculated value, C(I-4) is about to be stored to memory at the same time that additional pairs of operands are being transferred from memory into the input buffers. Note that there is a linear sequence of operations that is applied to each data value in succession, just as in a scalar (serial) machine except that parallelism is introduced by the overlapping of these operations for successive elements in the vector.

This mode of processing is often compared to an assembly line or to the flow of a liquid in a pipeline. In fact, the tie between vector processing and pipelined architecture is so strong that the concept of vector processing is sometimes presented as if it required pipelining. However, this need not be the case, since a machine could be designed in which a vector add instruction was implemented by giving one pair of elements from the input vectors to each of a huge number of microprocessors, operating strictly in parallel.

The division of some operations into a number of small steps (which may be overlapped in a pipelined manner) is called segmentation. This sort of pipelining is used to speed the operation of the Cyber 205 in many different places, including the scalar processor. For example, the instruction issue unit is implemented as a pipeline with three segments, so that the decoding of several instructions can proceed in parallel (parallel processing). Similarly, most of the functional units are segmented, the principal exception being the divide/square root/convert unit.

4.0 State-of-the-Art in Surface Coal Mine Modelling

An area of great concern and interest in surface mining is the geotechnical stability of natural and man-made structures. This section has been written to bring the latest applicable technology in this area to the attention of geotechnical engineers.

The past two decades have been witness to tremendous growth in numerical methods for the solution of problems in engineering science. The popularity and versatility of these techniques have been greatly enhanced by the availability of the large high-speed digital computer.

4.1 Model Classification

Today there is a growing awareness of the need to perform practical geotechnical analysis using microcomputers, mainframes and large scale computing facilities like the supercomputer. Before one can analyze the potential applications of computer modelling techniques to surface mining problems, it is necessary to have some general knowledge of the model classification schemes in use in geomechanics and geotechnical engineering. Definitions of the terms used in this discussion are contained in the Glossary.

The simulation of mining or processing is a synthesis of many disciplines, such as geomechanics, mathematics, thermodynamics, continuum mechanics, experimental techniques, numerical techniques, discretization methods and computer technology. Geomechanics and its associated mathematics are of particular interest to this discussion.

Geomechanics is the science of (macroscopic) displacements and forces in the technically relevant part of the earth's crust: soil and rock. The range of applications of geomechanics is considerable, and, because of technical expansion, difficult to define. Geomechanics is more complex than other branches of technical mechanics (for instance, hydraulics or the theory of elasticity) because of the relevant properties of the materials involved: soil and rock can quite justifiably be listed among those substances whose structures and reactions are most complex. This complexity leads to innumerable mathematical problems, so a large spectrum of applied mathematics and computational techniques are being used in geomechanics.

4.2 Numerical Methods in Geotechnical Engineering

The importance of the numerical aspects in modelling of mine structures has become increasingly more evident in recent years. The modelling efforts may be viewed as one aspect of the more extensive process of developing simulation models for mine planning systems (see Figure 11[14]). Modelling is much more than just curve-fitting of experimentally observed results; it normally employs the numerical methods of finite differences or finite elements. This author would like to emphasize the importance of these numerical aspects, since proper formulation and numerical implementation of a system can yield high rewards in terms of applicability of theory, economy of computations, and reliability of results.

In the past, soil and rock mechanics were considered essentially empirical disciplines. The enormous complexities encountered in natural states of geologic media can make analytical closed-form approaches very difficult. Researchers imparted scientific and mathematical bases to many aspects of these approaches; solutions were often obtained on the basis of differential equations that were assumed to govern the physical systems. A large number of simplifying assumptions were made to obtain closed-form solutions. Although this approach has provided useful solutions for many practical situations, it cannot yield realistic solutions for practical problems involving such complexities as nonhomogeneous media, nonlinear material behavior, *in situ* stress conditions, spatial and temporal variations in material properties, arbitrary geometries, discontinuities, and other factors imposed by geologic characteristics.

Fortunately the geotechnical engineer has been one of the first to recognize the usefulness of the newly developing numerical methods capable of accounting for a number of these factors. Consequently, in the last two decades, applications of numerical techniques to soil and rock mechanics problems have grown at a fast pace.

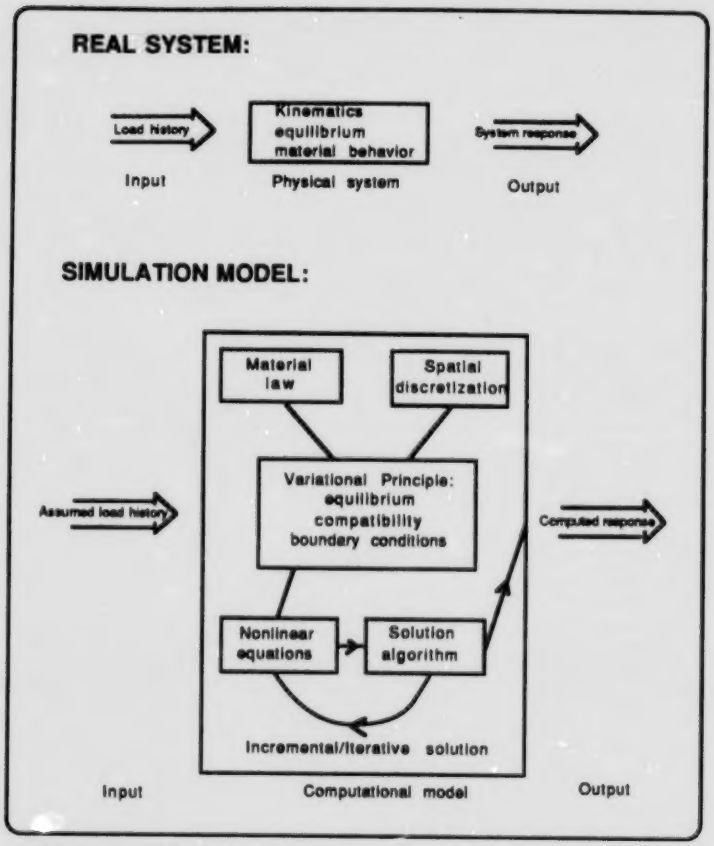


Figure 11 Relationship between real systems and computational model

Illustrating this growth was a conference on numerical methods in geomechanics held in Japan in 1985. The following geomechanical aspects of numerical techniques were considered:

- numerical techniques and programming
- constitutive laws of geotechnical materials and interfaces
- rock hydraulics
- earth structures and slopes
- dynamics and earth quake engineering
- mining applications
- use of microcomputers

Discussion at this conference revealed that finite element and finite difference methods seem to be the most common procedures employed by geotechnical engineers. A number of other numerical schemes (e.g., numerical integration of governing equations, method of characteristics, and the boundary-integral-equation method) have also been used. Some of the common procedures are shown schematically in Figure 12[15].

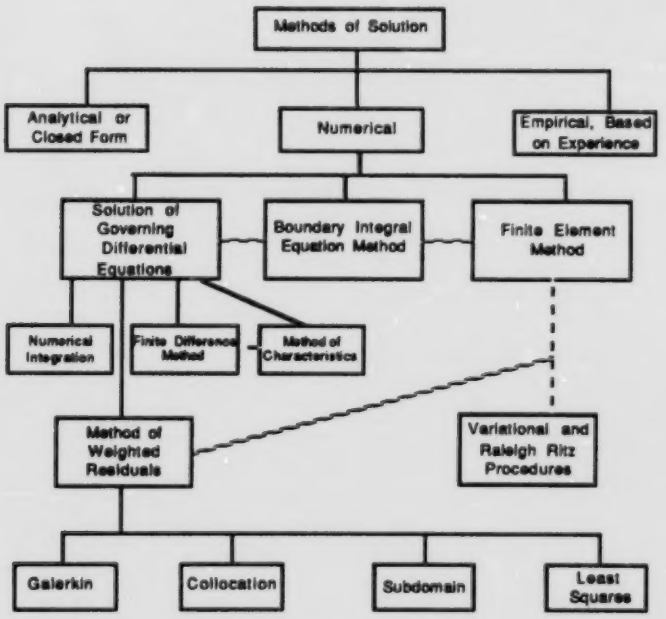


Figure 12 Numerical Methods

4.2.1 Finite Element Methods in Geotechnical Engineering

In the last twenty years, both theoretical developments and applications of the finite element method have grown tremendously. The geotechnical engineer was quick to recognize the usefulness of the finite element method for solution of complex problems that had defied conventional methods. Often on the basis of intuitive considerations, the engineer has exploited the power and potential of this method. Unlike the finite difference method, which came to the engineer with a considerable mathematical basis already existing, the mathematical characteristics of the finite element method had not been established fully.

Most numerical methods are based on the principle of discretization. In simple terms this can be defined as a procedure in which a complex problem of large extent is divided – or discretized – into smaller equivalent units or components. Discretization can take different forms: in the finite difference method, for instance, we can consider that the basic governing equation is discretized, whereas in the finite element method the physical body or continuum that constitutes the system is discretized.

Before the era of the finite element method, the finite difference method was perhaps the main numerical technique employed in geotechnical engineering. Although the finite element method possesses certain advantages over the finite difference method, the latter is more suitable for certain classes of problems. Here, however, we will concentrate on the finite element method because it is widely used for solving geotechnical problems.

Problems in geotechnical engineering can be classified according to certain categories (as shown in Table 2[16]). Some elementary problems and their corresponding differential equations are included in Table 3[17] as examples. There are three basic categories of models: steady (or equilibrium), transient and eigenvalue. Various combinations of these also occur in practice. Each of these methodologies has its strengths and weaknesses, however, if there is any discernable trend in the development of geotechnical engineering models, it is the gradual rejection of trial and error analytical techniques. The applied mathematical and computational techniques currently being used in geotechnical engineering are proving insufficient time and again. The move is now on towards finite element models. This is shown in Table 4[18] based on a survey of boundary value problems in geomechanics.

Table 2 Categories of Problems in Geotechnical Engineering

Steady or Equilibrium	Transient or Propagation	Eigenvalue
Static stress-deformation analyses for foundations, slopes, banks, tunnels, and other structures	Stress-deformation behavior of foundations, slopes, banks, tunnels, and other structures under time-dependent forces	Natural frequencies of foundations and structures
Steady-state fluid flow	Visoelastic analysis	
	Consolidation Transient fluid flow and dispersion	
	Wave propagation	

Table 3 **Some elementary problems and their corresponding differential equations**

Problem	Category	Equation
Two dimensional Steady flow or seepage in porous rigid media	Steady, or equilibrium	$\frac{\delta^2 u}{\delta x^2}+\frac{\delta^2 u}{\delta y^2}=0$ (1-1)
One-dimensional consolidation	Transient	$\frac{\delta^2 u}{\delta x^2}=\frac{\delta u}{\delta t}$ (1-2)
One-dimensional wave propagation	Transient	$\frac{\delta^2 u}{\delta x^2}=\frac{\delta^2 u}{\delta t^2}$ (1-3)
Natural frequency of footing	Eigenvalue	$m\frac{\delta^2 u}{\delta t^2}+ku=0$ (1-4)

Here u, the (unknown) dependent variable, can take various forms (e.g. fluid potential, pore water pressure, and displacement); m is the mass and k is a constant.

Table 4 A survey of boundary value problems in geomechanics

Rate of Dissipation			
Zero Equilibrium States	Constant Stationary Processes	Decreasing Stabilizing Transitions	Increasing De-stabilizing Transitions
Elastic*	Elastic Vibration*†	Transient Vibration*†	Plastic Collapse†‡
Pseudo-elastic	Potential Flow*	Diffusion*	Plastic Softening†‡
Elastic With	Plastic Flow†‡	Consolidation†	Brittle Failure†‡
Limit Condition*†	Viscoplastic Flow†‡	Elastic - Ideally	Liquefaction†‡
		Plastic Deformation†	
		Plastic Hardening†‡	
		Creep Relaxation†‡	
		General Coupling‡	

State of Development of Finite Element Methods (1985):
* FEM exist and are applied in practice
† FEM exist and are applied in research and practice
‡ FEM exist and are applied in research

4.2.2 Factors Influencing Numerical Analysis

The final aim of any numerical solution procedure is optimum accuracy, reliability and economy. Figure 13[19] shows a schematic representation of the factors that should be considered in arriving at the most suitable numerical scheme. In geotechnical engineering, the physical factors can include idealization or discretization of field situations which provide satisfactory precision of continuity of flow in a layered rock mass system. Adequate and sufficient fine-mesh layouts become a factor for situations involving stress gradients in an excavation problem. Examination of such numerical characteristics as convergence and stability should be considered for a general procedure. Human factors are related to subjective consideration when defining the problem and choosing alternatives. Both software and hardware aspects of the computer used can also influence the numerical solution.

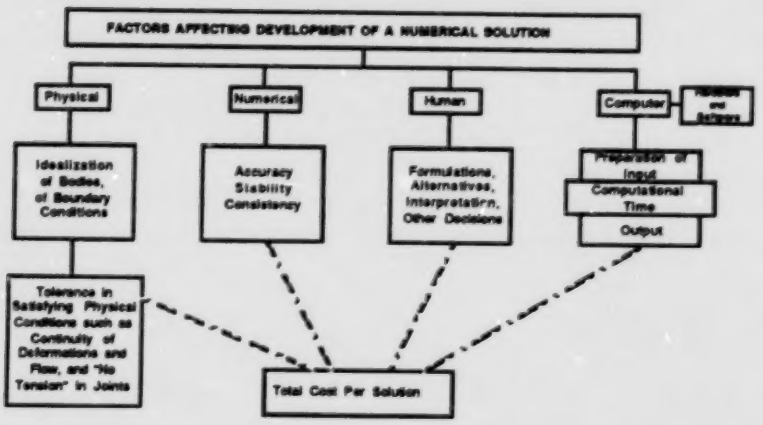

FACTORS AFFECTING DEVELOPMENT OF A NUMERICAL SOLUTION
Physical
Numerical
Human
Computer
Idealization of Bodies, of Boundary Conditions
Accuracy Stability Consistency
Formulations, Alternatives, Interpretation, Other Decisions
Preparation of Input
Computational Time
Output
Tolerance in Satisfying Physical Conditions such as Continuity of Deformations and Flow, and "No Tension" in Joints
Total Cost Per Solution

Figure 13 Factors in development of numerical method

Numerical methods have reached a high level of development. We believe that evaluation of available schemes leading to optimum design should be pursued vigorously. At this time, use of numerical methods as a basis for mine design is limited to a very small class of problems. The methods have been found to be useful as tools of analysis; they can be used as alternative means of design and verification of conventional methods. Although many models are generated, modelling is a difficult pursuit and requires considerable human and computer effort.

The popularity and versatility of numerical analysis has been greatly enhanced by the availability of the large high-speed digital computer. Supercomputers provide viable solutions to a diversity of mathematical or mechanical problems in engineering analysis that previously defied solutions by conventional computers. As a result, supercomputers have served as an enabling technology for prediction and modelling, allowing us to tackle complexity that is otherwise intractable.

5.0 Advanced Computer Hardware and Software Technology: Applications To Mining

Surface coal mine geotechnical modelling is a computational tool mine planners use to model the physical processes involved in coal and oil sands recovery. This section describes how advanced computer hardware and software technology are helping the mining industry to

- increase the ability of mine simulators to handle problems of more realistic size and complexity,
- improve the efficiency, accuracy and certainty with which surface mining geotechnical engineering problems can be solved using models,
- reduce costs and thus increase the value of geotechnical engineering models, and
- expand the availability and usability of simulation technology to non-specialist management and engineering personnel working in the operations offices of mining companies of all sizes.

The software directory prepared for this report shows that Canada is reasonably well-off in terms of surface coal mining geotechnical modelling applications, as well as models which look at the various related aspects of surface mining. The major gap in Canada appears to be the lack of operational models which emulate the geotechnical processes (although university researchers have done some work in non-linear and 3-D models in this area) and in other models which optimize surface mine design and improve production. These gaps have already been recognized, and some preliminary work has been done at EMR (Serata Geomechanics), but no operational model is imminent. In western Canada we also need to address issues such as plains and foothills coal deposits as well as large scale surface mining problems encountered in oil sands.

Although the U.S. seems to be better served by many geotechnical engineering models, there appears to be a number of drawbacks to the models which are currently in use there. One of the most interesting models that has been developed anywhere is being produced at the Department of Interior in the U.S. Unfortunately, although the work is proceeding at a rapid pace, it is still some way from completion and applies to a very limited area in

the U.S: a number of these models are developed for specific areas such as Ohio, Pennsylvania and West Virginia. Again, these apply to underground situations. Even the model which is most advanced in terms of operational capabilities (i.e., Eagles Modelling System at Morrison and Knudsen, Ltd.) has enough shortcomings that even the users in industry are in the process of replacing it with substantially improved versions.

Demand in Canada will be particularly heavy for coal and oil sands mining software design and development, and will increase as the number of large-scale computing sites grows. When examined the software available for the coal mining industry in the literature survey, it was found that the lack of application software on supercomputers has been a significant barrier to their adoption and use by the industry. Concern over the availability of all types of software (not only applications software) for large-scale computing continues to be a critical issue and will worsen in the near future with the proliferation of significantly different architectures.

Applications and systems software is available for conventional machines, yet in some cases does not fully use the capabilities of current vector machines. The breadth of systems and applications software appears insufficient to satisfy both current and projected demands generated by the mining industry.

5.1 Model Assessment

It is the intent of this report that the results be useful for persons charged with the task of evaluating pit slope or similar models on a supercomputer. For model evaluation there are no generally accepted standards or methods. Hence, one can perceive the need to expand upon lessons learned from the previous evaluation of software (such as that used in geomechanics and geotechnical engineering) since computational models being used today are often the by-products of previous generation computers.

A portion of any evaluation involves assessing the theoretical foundations of the technology either developed or adopted during the formulation of the model. The final report on a model evaluation study should provide an independent assessment of, among other things, (1) whether or not and under what conditions the potential user should use the model for the purpose described, and (2) how the model should be used.

Two aspects were examined regarding the modelling process using the supercomputer. Firstly, the possibility of current computational research projects to be run much faster with a wide range of parameters thus giving greater precision to the solutions obtained. Secondly, the ability to design and execute those projects that could never be contemplated in the past due to the shear scale of the computations involved. Preliminary results discussed in the case study section indicate that the supercomputer can accelerate the production of results faster; it provides an opportunity to begin solving some of the difficult problems in mining applications.

The steps of model assessment should include the following:

1) Obviously, one must first find an appropriate model to be assessed. As far as numerical techniques and software availability are concerned, the mining engineer has to make extensive use of outside help. For the required modelling techniques in slope stability, seepage analysis and rotational shear, the techniques from other branches are being successfully adopted (as demonstrated by the current software available to mine planners).

2) Next, the model must be modified to fit the situation for which it will be used. An example of this is the development of geomechanics for rock fissures (special elements for propagating cracks in soil and rock) which is still in the initial stages. In this case the discretization in time is being done by the difference method.

3) Numerical convergence, uniqueness and stability of the model must then be judged, although this is not always easy. If a problem is not well-posed mechanically, numerical convergence and uniqueness cannot be expected either. In individual cases, we performed numerical tests as a minimum requirement wherever possible.

4) The interpretation of the output from current software is also an important consideration for a technical evaluation, particularly for the results from mining software using finite element methods.

5) Finally, the economics of numerical methods are very important for the whole of geotechnical modelling practice. Non-linearity and complicated geometry often cause the finite element methods to be quite expensive on microcomputers and conventional mainframes. For cost effectiveness, the possibility of using vector processors for such non-linear solutions is very apparent.

5.2 Improving Surface Mine Design Engineering Decisions

Optimized surface mine design is founded on geological, geotechnical, mining and economic data. Traditional design procedures generally consider geotechnical constraints at the pre-feasibility or main design stages. The development of mine design computer software for conventional mainframes made little attempt to integrate geotechnical studies into what the mine planning engineer saw as a combination of geotechnical, hydrological and economic exercises. The recent enhancements to such software in the form of supercomputer two- and three- dimensional interactive graphics workstations will be invaluable to the integration of slope design. Moreover, pre- and post-processing software we examined during the feasibility phase of this study, will enable the engineer to be in control of computer analysis.

Commercial mine design software generally are based upon the development of 3-D geological block models using inverse distance or geostatistical methods. Generally, the geotechnical engineer is required to use pit depth or seam data to determine working and ultimate slope design with separate stability analysis software. The geological block model, however, also permits the development of a geotechnical model of the deposit and host rock mass. Blocks can contain data on rock mass material strength, structure and hydrological factors. This report considers the potential for improved design based upon such a model. Stability analysis and seepage analysis programs developed in pit slope programs were evaluated to highlight preliminary areas where stability is acute. Detailed stability analysis could be undertaken by 2-D or 3-D limit equilibrium methods on a supercomputer using vectorized versions of these programs. The opportunity to automate the design process exists with pre- and post-processing software and interactive graphics workstations.

The integration of both geotechnical and hydrological factors into the design process will require computationally intensive mining models. It also suggests the possibility of applying rapidly developing supercomputer technology to the mine design process. This is possible as an overall design system or as a sub-system of geological modelling, geotechnical studies, and optimum mine planning. Since this report focuses on surface coal mine stability assessment using supercomputers, it reviews existing software to assess how vectorization would improve software capabilities, potentially offering the basis of a design system to interact with geotechnical and mining models.

5.3 Desirable Features of Geotechnical Analysis

Today's supercomputers are sufficiently powerful to perform meaningful geotechnical analysis of rock mass excavations and surface coal mine geometrics. In this report we describe practical applications of three computer programs that we use for evaluation (See Case Study Report in the Appendix). These programs are

- Stability Analysis: two dimensional finite element code
- Rotational Shear: two dimensional finite element code with graphics output
- Seepage Analysis: two dimensional finite element code for groundwater modelling.

In order to demonstrate the feasibility of using a supercomputer for a particular application, the above programs were selected. (These were the only models available to us during this study.) We considered four fundamental components which we feel are a must for this type of study. These include the following:

1) Supercomputer Speed: This being a feasibility study, it is not practical to optimize a complete application to attain the full potential of the machine. However, a reasonable goal one might set is to pick a subset of a problem for analysis. Suitable for this purpose is a comparison of run timings for the seepage analysis program 'as is' code to equivalent calculations performed using a pre-vectorized library routine. In the next phase, it will probably be necessary to become involved with a fair degree of detail, particularly in terms of algorithms.

2) Graphics Output: Supercomputers have become tools of vision. The voluminous numerical results of extensive computations can be shown graphically: animated simulations that truly open the door of understanding geological modelling, surface geophysics, pit slope analysis or mine design. Assisted by these multi-dimensional animated graphic displays (that change as the variables change) the human mind can better grasp the significance of numerical data.

3) Use of Real Field Data: Data intensive problems (as well as non-linear problems) involving sudden unpredictable change in geology or engineering field data, become solvable with supercomputing. Determining the behavior of rock mass is the type of problem that is not amenable to field experiments or cost savings, but can be successfully approached via a combination of real field data and supercomputing.

4) Supercomputer Environment: Very specialized capabilities need to be provided to allow system users to gain full advantage of the immense processing power available on a supercomputer. The implications of this have a direct impact on transferring programs from other scalar facilities. Case studies described in this report addresses some of these issues.

5.4 Software Currently Available on the Cyber 205

The following sets of software reside on the Cyber 205 at The University of Calgary:

- Systems software: includes the Cyber 200 Virtual Operating System(VSOS), an ANSI 77 FORTRAN compiler, a C compiler, a loader and an object library editor.

- Utilities: consist primarily of programming tools to assist in conversion, debugging, and vectorization of software.

- Mathematical libraries: contain subroutines (many highly vectorized) which may be called by a user's program. A few of the libraries offered are IMSL, ITPACK and MAGEV.

- Application software: at the present time is primarily in the petroleum reservoir simulation area. Programs include VIP and MVIP (from J.S. Nolen and Associates) and ISCOM (from the Computer Modelling Group). A number of other application programs, such as ABAQUS, DISSPLA and SPSSX should be available on the Cyber 205 in the near future.

5.5 Computers and Surface Coal Mine Modelling Applications

A wide variety of software is necessary to run any large computer mine modelling system. Some broad categories of software are as follows: geological evaluation, mine planning and design, mine simulation, geotechnical evaluation, hydrologic evaluation, environmental planning and computer aided design. Application programs are the software developed to solve specific problems. They range in scale and purpose from small, relatively simple programs designed to solve a specific problem once, to large programs employed by users to solve a variety of problems.

Underlying these levels of software is a rapidly developing body of computational theory flowing from mathematics and computer science. Computational mathematics, for example, helps to develop improved methods by examining how basic methods for calculating solutions to equations behave in terms of efficiency and accuracy. In particular, computer scientists and mathematicians are only beginning to understand how to optimally use the types of highly parallel design computers that architects are exploring. As such knowledge is developed, it will lead to more efficient use of existing supercomputers.

Analysis and evaluation of natural resources requires processing quantities of data and using complex mathematical, statistical and geostatistical models (as discussed in Section 4.0). When multiple alternate solutions exist, the ability of the mining industry to select the most viable alternative in the least time is not possible without sophisticated computer systems and models (from micros to mainframes). Further sophisticated technology is now available to the user through networks and distributed processing, with a savings of both time and money.

The purpose of this section is to describe a number of areas in which computer models are already in use. Although not all areas need supercomputer technology, we want to emphasize only those related areas best suited for supercomputer application. The other areas are well served by existing hardware/software combinations.

5.5.1 Geological Modelling

Resource modelling and analysis systems provide users with in-depth and timely resource evaluation techniques. Modelling programs available on conventional machines evaluate flat-lying bedded deposits, steeply dipping bedded deposits and massive non-bedded deposits for both surface and underground mining situations. Software developed in this area utilize statistical, geostatistical, trend surface, block definition and polygonal influence methods of evaluation, and interpolation by these methods provides mathematical representations of the resource. The model can then be examined and evaluated through structural contour maps, isopach maps, iso-quality maps, data distribution curves, and variograms.

Geological computing modelling (resource modelling) software provide

- Digital Terrain Models
- Geologic Modelling and Mapping
- Geologic Data Manipulation
- Resource Evaluation
- Reserve Estimation

Although not all areas mentioned require supercomputer resources, areas currently being examined for supercomputer use include Geologic Modelling and Mapping and Reserve Estimation.

5.5.2 Mine Planning And Mine Design

Within the last few years, cost-effective vector and multi-processor supercomputers have provided wide-ranging applications in many fields. Sophisticated computer graphics are being used to facilitate many of these applications that involve large, multi-dimensional data sets and outputs of complex computer simulations.

This section explores the synergism between supercomputer capabilities, such as exist on the Cyber 205 and the Cray, and imaging and graphics systems. Potential areas of application can be drawn from examples from surface and underground mines: coal, oil sands, potash and lignite. Mine planning and design can be improved by combining image processing, image understanding, and image synthesis techniques for presentation and interaction with complex data sets.

Mining engineers may choose among polygonal models, block models, and cross-sectional analysis models to describe a deposit. Supercomputing applications involve complex data sets and massive amounts of potentially visible information that lends itself to a complete evaluation of each alternative design in a minimum amount of time. Based on the resulting detailed information, planners can select optimal

- Computer aided drilling and blasting design
- Pit Advancement
- Quality Compliance

Model and simulation validation, interactive exploration of multi-dimensional datasets, and dissemination of results to larger audiences are examples of new applications of graphics and imaging technologies.

5.5.3 Mining Equipment Simulation

A whole range of sophisticated computer models has been developed to simulate mining equipment operations. These simulation programs draw on library files and proven operating characteristics for different brands of equipment. These computer programs use this database to evaluate a mine and select the most suitable equipment for the job by simulating draglines, shovels, trucks, drills, bucket wheel excavators and conveyor belts.

Another application of tightly coupled supercomputing and graphics is the modelling of complex mine simulation systems to assist mine planners in forecasting

- pit sequencing and configuration designs
- blending and optimization schemes
- mine materials handling
- dragline design specifications
- bucket wheel excavator specifications
- spoil configuration and reclamation modelling
- ventilation design

5.5.4 Hydrological Factors

In response to the increasing emphasis by regulatory agencies on the impact of water resource projects on the environment, hydrogeologists and planners use supercomputers to run large scale models. Sophisticated software, that decrease clients' evaluation time and total project cost, have begun to appear on supercomputer sites. Computers of ten years ago were insufficient to achieve a brute force solution to these problems. Today's models have the capability to define and resolve such complex hydrological issues as

- Aquifer evaluations
- Runoff/Flood studies
- Groundwater modelling
- Surface water modelling
- Dewatering designs
- Water Quality Assessments

5.5.5 Slope Design and Seepage Analysis

Being able to quickly process computationally intensive slope design and seepage analysis models enhances a mining engineers ability to understand and predict rock mass behavior. These models typically forecast changes in pit slope geometry, groundwater pressure and directions, and probability of failure. Output from the model includes stress contours (horizontal, vertical, shear, maximum principal, minimum principal, and maximum shear stresses) and equipotential surfaces (groundwater pressure).

The problems in trying to understand the results of this model are typical of many supercomputer applications. Massive amounts of spatial and temporal data require sophisticated tools to allow the user to distill information from this output. The user must be able to access specific data elements in an organized and efficient way. He must also be able to see several geotechnical and economic pieces of information rapidly and simultaneously. This allows him to assess qualitatively the behavior of not only the simulation (for debugging) but also of the frequently complex relationship between simulation variables. The computer models identified for development to run on the supercomputer will be valuable additions to the software library,

with time saving tools in:

- rock mechanics
- soil mechanics
- slope stability
- tailings disposal
- abandoned site evaluation
- hazardous waste disposal and storage
- industrial site evaluation
- mine site evaluation

The software essentially exists in a number of areas for use in much of surface coal mining, but not all of them are suitable for vector computers. Some are, and some will have to be, selected by the practitioners in industry. Ultimate decision to set priorities rests with those in the field. As an academic effort we are soliciting their help in clearly identifying what is of immediate use to them.

5.5.6 Environmental Impact Planning

There is a significant interest in accurately depicting landscapes and terrains for environmental impact studies, mine planning systems and pollution control. These visual simulations are based on satellite imagery and digital terrain elevation data. The algorithms for generating such images are well documented in the field of computer graphics. The process involves texture-mapping the imagery onto a mesh of elevation data and viewing the results from different angles. The databases of the Earth Resources Laboratory Applications Software (ELAS), Environmental Mapping Information System (EMIS), Environment Canada, Canada Land Data System (CLDS) and Geological Survey of Canada's, National Coal Inventory databases are extensive. Accessing the desired data and performing the computer graphics operations on multi-megabyte data sets can, however, burden conventional hardware.

Pre-processing the relevant data using a high-resolution computer simulation program consists of more than 250,000 polygons. Rendering the images, including grid manipulation and display can be accomplished with a supercomputer. Traditional image processing and the emerging field of image understanding are both computationally intensive and lend themselves to advanced computing architectures. Here we cite four such applications involving environmental planning:

- geotechnical application of remote sensing
- ecological investigation
- water pollution
- reclamation

5.6 Applications to Oil Sands Mining

An oil sands industry requires very large mining operations compared to coal, as illustrated in the Fort McMurray area by Suncor and Syncrude. The amount of material that must be handled in the extraction plant can exceed 100 million tonnes per year. Extraction, then, is an important area to concentrate on in terms of cost savings. "The big push is to get higher utilization out of the mining equipment, and secondarily to reduce the cost of removing the overburden."[20]

Surface mining has advanced because of developments in mining coal and lignite. It is suitable for a resource if it is done on a large scale and allows low-cost removal of most of the resource. The thickness and extent of oil sands present a new problem for mining engineers. First generation technology for oil recovery from tar sands through surface mining and above ground processing is being successfully practiced commercially. The major portion of the tar sands resource will have to be processed by applying *in situ* techniques. *In situ* processing has not been commercialized on tar sands and is currently limited to field tests by Alberta Oil Sands Technology Authority (AOSTRA). Novel ideas dealing with radio frequency heating and a combination of mining and *in situ* methods have also been proposed but have not been tested on substantial scales.

A number of industry-sponsored projects relating to oil recovery from tar sands and heavy oil sources is currently underway. However, the support of field projects will be appropriate only when the federal government is involved as a partner. In our opinion, computer library programs can be designed and developed specifically to meet the needs of management for developing efficient, productive and cost-effective surface and *in situ* mining of oil sands.

Research needs of surface mining include studies of slope stability, dewatering on a large scale, methods of placement of spent bitumen in the pit, and a plan for location of pits for maximum resource utilization and minimum environmental costs. This information will be useful in developing federal mining policies.

6.0 Supercomputer Performance and Software Issues

Engineering analysts who address the supercomputer as they would a traditional mainframe are apt to produce costly results. In the past, applications analysts, applied mathematicians, numerical analysts, and software specialists have all contributed to the success of a given project. They made their respective contributions while working independent of each other.

For example, an engineer might develop a mathematical model, then pick up a numerical algorithm from a software library. The numerical analyst could develop a solution algorithm without concern of the actual hardware on which the problem was to be solved. The computer hardware designers and architects could build machines that were basically general purpose and conveniently ignore the applications the computers were created to run.

The supercomputer has broken the barrier between these comfortably exclusive fields of expertise. While providing much greater computing power and memory, the new machine also introduces a different architecture and forces the engineer, programmer, and numerical analyst to re-evaluate computational algorithms and even modelling assumptions. The functions of the three separate groups are linked. On vector computers, performance results demand that computational models be matched with computer architecture. The inter-relationship between applications, algorithm, and architecture holds, regardless of scientific discipline.

6.1 Algorithm Development

The supercomputer has turned the typical engineering problem analysis procedure upside-down. Before supercomputers existed, the engineer performed geotechnical engineering analysis through a manual process which involved reducing the original detailed model to a coarse smaller and manageable size. Many geotechnical engineers in the 1970s were content using outdated numerical methods because they were not attempting to analyze larger models -- until modeiling entire mine areas became beyond the scope of available computers. For larger models the use of the finite element approach to geotechnical engineering problems was tedious, time-consuming and professionally demanding, adding to the design cost of a structure while detracting from the precision of its analysis.

The supercomputer has made it possible to solve an original, detailed engineering analysis problem directly, performing the mechanical aspects of the task and reducing human error. But the job requires advanced algorithm work. With supercomputers even moderate increases in performance due to algorithmic improvement can turn into significant economic gains.

In terms of opportunities to use supercomputers efficiently and creatively, a cooperative approach is necessary. Other considerations worth including in a modelling structure for supercomputers are

- software issues and application specific algorithms,
- data management, and
- graphics.

To exploit the full power and benefit of supercomputing, the user must understand the underlying architecture, be aware of new algorithm developments, and comprehend the computational structure of application code.

Software is an important determinant of the efficiency of the supercomputers and the types of problems that can be tackled with them. For these reasons, an investment in algorithms and software development is integral to any large-scale computation program.

6.2 Software Development Issues

The availability of software for large-scale computing continues to be a critical concern. Government efforts are necessary to tackle this software problem. Greater availability of time on supercomputers as a result of federal investments and provincial programs can both improve and ease current software demands. As more and more users turn to supercomputers to solve their scientific and engineering problems, new software will be generated, increasing the usefulness and capabilities of the machines. Once a network is in place, those who use it will share software as well.

At the same time, until more software is developed, users will inevitably be frustrated by limited access to the machines and the lack of standard applications "libraries". Until more engineers use large-scale computers for their work, the lack of applications software will remain a problem; manufacturers have not traditionally developed a substantial base of software (including applications software) for their machines. In fact, it has been stated:

"... it has taken over 5 years to develop software to efficiently support and utilize vector technology."[21]

Transportability of software from machine to machine and site to site is also needed to encourage users to experiment with advanced scientific computing facilities, and thus build a base of new users. "We should be in a position where we can make it very easy to move from one machine to another."[22] Because there is no comfortable bridge on which to move code/software from machines in use (e.g., a VAX) to a supercomputer, the mining industry community may withhold its support, to avoid delays in performing research and because of the complexity of undertaking the research on a supercomputer. As noted in the U.S. Federal Coordinating Council on Science, Engineering, and Technology Panel report, August 1985,

"... Researchers may not use this important scientific tool if its use proves difficult to learn, frustrating and generally inconvenient."[23]

The nurturing of new architecture will also bring a host of software problems. The new architectures demand "...a fundamental rethinking of problems and a rather fundamental rethinking of strategies"[24] in the creation and development of algorithms. A new type of research activity is necessary. The recommended approach to tackle software needed for new architectures is the formation of interdisciplinary teams consisting of mathematicians, computer scientists, and engineers from disciplines with problems to be solved, .

Software is an important determinant of the efficiency of supercomputers and the types of problems that can be tackled with them. It also influences the design of the next generation of machine. For these reasons, an investment in algorithm and software development is integral to any large-scale computation program.

The final two issues are the growing shortage of personnel needed to meet the current and projected software demands, and the matter of the need for supercomputer software to have better definition and resolution.

7.0 Surface Coal Mining Geotechnical Modelling Applications

7.1 Mining Industry Level of Awareness

A major objective of any national supercomputer modelling exercise would be the analysis of the impact on advanced mining technology through an industry awareness campaign. It will probably be necessary to become involved to a fair degree of detail by considering both industry priorities and types of models required. The motivation behind employing an industry awareness campaign is not simply so that model's results can be reported by particular industrial sectors (although with mining interests sharply defined as they are in Western Canada this too is important). This campaign could also ensure that specific information and significant differences concerning geological resource assessment, mine design and planning, production optimization, scheduling and other specifics could be accurately incorporated in the models.

7.2 Collaborative Modelling Efforts

Computing requirements like management information systems (such as the payroll, material management, maintenance planning and inventory control) are more difficult to incorporate in today's supercomputer model and perhaps can safely be ignored or otherwise treated on conventional general purpose computers. The distinction between different surface mining practices in plains and foothills coal fields is important, and perplexing because of the variational aspects of surface mining activities. A reasonable approach might be to have different models on a supercomputer for each type of mining. The problem then evolves into one of bringing common elements together (i.e., geotechnical aspects of coal vs oil sands). Joint products could also be considered in other areas (as discussed in Section 5.0). The data required for the study was provided by two coal mining companies in Alberta as previously mentioned. Also, a number of organizations in the U.S.A, Australia and Canada supplied literature, programs , data and documentation for this study.

In terms of surface coal mining geotechnical applications, it should at least be possible to separate plains coal mining from foothills mining problems. Modelling differences, even within conventional mainframes, may not be worth considering. Other kinds of distinctions that would be worth including in a modelling structure would be

- scientific and/or technical complexity (engineering analysis)
- software or algorithm capabilities (simulation, optimization and mathematical programming)
- user friendliness (graphics, conversion and programming tools)

7.3 Scalar vs Vector Models

Although some scalar models are included in a broader surface coal mining geotechnical applications framework, vectorization and development of models to fit current technology is probably a long way off in the future for CANMET/EMR. Before we can have a supply of vector models, we must first have the component pieces. While the pit slope programs are being evaluated, there is lot of work to do before the complete mining vector library pieces are equally well developed.

A reasonable approach would be to treat each piece of vector software on its own merits. It could reasonably be assumed that either the industry is a potential user or that the government would set priorities in consultation with industry and mining associations. The sponsorship of joint university/industry efforts (to further develop application areas such as seismic/borehole geophysics, material handling and mine design) might result in a vector library collection in order to address Canadian mining requirements. This software library would include not only geotechnical applications but also many surface coal mining applications – from geological assessment to final delivery to market.

Once a set of priorities and associated software requirements has been put together over a given time-frame, the development of each of the separate priority areas can be done more-or-less independently, without the need to be preoccupied with the issue of vectorization — the primary concern with most "supercomputer" models. Although it will still be necessary to make sure that the assumptions are consistent across the board, this approach is considerably less ambitious and costly than one which would involve setting up massive, long-range, separate research structures. Nevertheless, a longer term goal of integration should always be kept at the back of our minds when developing surface mine computer models.

7.4 Seepage Analysis

The first priority on the pit slope geotechnical engineering side should be to get a reasonable representation of groundwater problems and their effects on the design of pit slopes. This should consider the movement of water through porous materials (such as soil and rock) and steady-state saturated flow through homogeneous isotropic rock mass (with constant known boundary conditions). At a later date it might be possible to become more sophisticated and develop a capacity for analyzing and handling both saturated and unsaturated flow simultaneously. Complex transient saturated-unsaturated flow through non-homogeneous anisotropic material into boundary conditions can be explicitly modelled and linked to slope stability analysis.

The current state of knowledge in rock slope engineering does not permit a precise definition of the groundwater flow patterns in a rock mass. Consequently, the only possibility open to slope designers is to consider realistic extremes (gathered from filed observations) and correlate them with model predictions (that are functions of computer results). The next step would be to assess the sensitivity of the slope to variations in groundwater conditions; this must be done in a supercomputer environment since it is not possible in either a PC or mainframe setting.

7.5 Slope Stability Analysis and other Priorities

Next in priority among the mining models for surface coal mining would be

- slope stability analysis,
- geological modelling,
- surface geophysics material handling, and
- some of the more traditional mainframe based simulation, optimization and mathematical models for scheduling, blending, processing and *in situ* mining, etc.

At any point in time in the development of these mining models (where one set of mining activity has been modelled but another has not) it will be necessary to make use of existing information and software to fill any remaining gaps in an analysis of necessary overall industry balances . It would be hoped that these gaps become smaller and smaller over time as they are gradually filled with better engineering analysis models of the mining process.

7.6 Steps in Geotechnical Modelling

The process of geotechnical modelling can be broken down into seven major steps. The first four steps deal with model selection and/or development. The last three steps involve applying a computer model to create a representative model of the rock slope under consideration.

Steps 1 to 4: Develop or select a model

1) Describe the physical processes to be simulated.
2) Develop a mathematical representation of the physical processes.
3) Develop a numerical solution to the mathematical representation. (This step has evolved from the initial use of scaled-down field models and the subsequent use of digital computer models based on analytical solutions to fundamental mathematical representations.)
4) Develop a digital computer program that incorporates the numerical solution.

Steps 5 to 7: Use the selected/developed geotechnical engineering model to to perform simulation to improve engineering design decisions.

5) Build a geotechnical model of the mine by supplying a physical description of critical rock slope problems, geological and groundwater information, and relevant mechanical properties of rock.
6) Fine-tune the physical description of the geotechnical model data supplied to the simulator by cross-matching past performance (running the simulator with the measured geotechnical problems and comparing observed performance variables against those calculated by the simulator).
7) Predict the engineering and economic impact of alternative geotechnical slope engineering management schemes (such as stability of rock slopes, production rate, and required artificial wall support such as anchoring and bolting).

7.7 Geomechanical Behavior

The issue of how to treat the relationship of the Stress, Property, Rheology and Deformation (SPRD) method[25] to design and analysis of slopes in surface mines is a difficult problem. Even in the most advanced U.S. geotechnical models, this problem is not handled satisfactorily. Finite-element programming models do not seem to be the full answer; they are both cumbersome and costly. Geomechanical stress deformation behavior (using rough order-of-magnitude approximations directly relating the stresses acting on a rock mass and its material properties to the deformation of rock slope) may be the preferred approach to handling the behavior of complex ground.

7.8 Methodology

It seems that, given mining industry requirements to include the effects of stress, rock properties, groundwater and deformation, there is a need to use a coupled boundary element/finite element type of model, with some rheological element and time-dependent components. General limit equilibrium methods are clearly less useful in situations with complex ground and a number of widely varying behavioral components. For any given level of detail, the stress, property and deformation type of approach has the further advantage of being suitable for large-scale computers.

At this time, the use of the traditional scalar mainframe approach, however, makes it difficult to test (on a supercomputer) the implicit behavioral assumptions.

7.9 Modelling and Field Data Availability

Although recognizing the importance of data availability in these kinds of analyses, the extra benefits gained by explicitly modelling field data through the use of Monte Carlo type simulations do not appear to be worth the very large extra modelling costs. It might be possible, however, to make a provision for adding this feature at a later date.

There is another way of handling data availability. It should be possible to obtain, from existing work at CANMET/EMR, the cooperation of the mining industry. If the pit slope model which is eventually adopted by CANMET/EMR is vector as opposed to scalar, it will be necessary to choose

among several alternatives in order to be consistent with other supercomputer requirements. Given the scalar methodology adopted by the pit slope programs, one could make three significant new advances in the computer implementation of geotechnical engineering modelling applications, resulting in an increased use of supercomputer technology. These advances are as follows:

- vectorized code to take advantage of the vector processing capability of advanced supercomputers
- modularized components that allow quick comparisons of alternative model description and/or slope design methods
- workstations software that permits input data preparation and output data analysis in menu-driven format, with excellent (colour) graphics display capability, even in a microcomputer environment

7.10 Conclusion

In relying on information and work that has already been done, the key words are "adopt and adapt". Where it is not possible or feasible to explicitly incorporate some of the work that has already been done in the modelling structure that we eventually adopt, we should strive to be in a position to explain any differences in results that may come out of the two different approaches. This is particularly important in making predictions from currently available software. That is, they should not deviate from the expected behavior when using field data in the same situation. This would provide a truly quantitative tool for the design of pit slopes.

8.0 Evaluation of Surface Coal Mining Software: Case Study Report

The purpose of this study was to investigate the feasibility of using a supercomputer for surface mining applications. To that end, CANMET/EMR Pit Slope programs and manuals were examined and identified the strengths and weaknesses of the various software in terms of their suitability for use on the supercomputer.

The finite element method applied to jointed rock masses has shown that many small load steps of many iterations are necessary to overcome the inherent nonlinearity of the method. This invariably leads to excessive core storage and computation time. The pit slope programs chosen for this case study illustrate the work required to adapt to a supercomputer environment.

The following key questions are of general interest in numerical modelling and the analysis of design in rock slopes:

- How can previously developed modelling methods be used in a supercomputer environment for design when so little information can be extracted from them?
- Are two-dimensional simulations adequate for rock slope studies?
- Is there any point in modelling problems when they are physically ill-posed and when field data is difficult to obtain for a supercomputer?
- How can a supercomputer environment help in the adoption of existing software and algorithms?
- What type of utilities, tools and interactive computer graphics will be necessary for numerical modelling work for geotechnical mining applications?

The case study was used to point out some of the strengths and weaknesses of currently available scalar software and identify the supercomputer environment suitable for future conversion and optimization work.

8.1 Conversion Implementation Summary

The initial evaluation process required the selection of a slope stability program for the TransAlta and Smoky River mining operations. This program had to be consistent with the following criteria:

1) accepts the available geotechnical parameters as input
2) performs seepage analysis for Highvale mine Pit No.3
3) simulates efficient slope design
4) schedules and reports design criteria for different operational conditions
5) is "user friendly" and makes use of interactive graphics.

The pit slope programs and documentation delivered by CANMET/EMR were identified as meeting items 1, 2 and 3 of these criteria, and were the basis for all software evaluation tasks.

The scalar versions of the pit slope programs were first implemented, as is, by converting them to FORTRAN 77 using the utilities on the CYBER 860 (CONVERT/F45). The CRISP utilities (a collection of tools designed to enhance the usability of the CDC/ETA Systems supercomputers) were used for checking and, wherever possible, to speed up implementation and conversion work. No attempt was made to fully vectorize and optimize the dormant software, although selected programs were converted to run on the supercomputer – a process which involved some basic vectorization. The findings are included in the section "The Benefits and Drawbacks of Vector Processing".

8.2 Systems Evaluated

Following is a list of the systems chosen for the evaluation process:

System	Developer	User/Status	Date
a) Slope Stability	Pit Slope, EMR	scalar code	1976
b) Rotational Shear	Pit Slope, EMR	scalar code	1976
c) Seepage Analysis	Pit Slope, EMR	scalar code	1976
d) PREDICT	GSC, ISPG	ISPG	1986
e) INCOIL	UBC	AOSTRA	1987
f) CONCOIL	UBC	AOSTRA	1987

In addition, literature from a number of software library packages was examined to obtain current information on engineering analysis, simulation and graphics. The items examined included ADINA, ABAQUS, BEASY, MEDSYSTEM, MINEX, etc. Particulars about these packages are contained in the Application Software Directory appended to this document.

a) Slope Stability

This system was developed in 1976 as a major project to produce the pit slope manuals by CANMET/EMR. It was expected to bring substantial benefits in mining efficiency through improved slope design. A noteworthy feature of the project was its cooperative nature – it was financed jointly by industry and the federal government.

Slope Stability is essentially a batch-operated system designed and developed for the mainframe computers that were available at the time. It handles memory, input/output and computational requirements in scalar mode, but has no interactive, online graphics capabilities. Furthermore, it is written in FORTRAN IV, which is no longer in common use and has not been maintained since the early 1980s. (It has been replaced by FORTRAN 77, which is considerably different.)

In our study,the Slope Stability programs were converted to run on the Cyber 205, and enhanced the output so that it was displayed in graphic form on a PC (the Macintosh) running a Tektronix emulator. The advantage of running this program on the supercomputer is that large models with many data elements can be processed quickly. The addition of graphic output makes the results easy to interpret, which is the major advantage of PC based systems. (The output of these programs begins on page 65.)

Work done in converting and running this code will be useful for developing either a two- or three-dimensional stochastic representation of rock slopes. The model used in our case study uses numerical approaches. It shows that the difficulties in representing nonlinear behaviour in a linear form are due to the shortcomings of the scalar algorithms used. Further improvements can be made using more recent algorithms on a vector computer to represent nonlinear stochastic characteristics.

b) Rotational Shear

This system was also developed by CANMET/EMR. It is also a batch-oriented, "modular" system. Individual "stand-alone" programs exist for reliability analysis of plane and rotational shear.

The graphics interface program has its origin in the mid-1970s and is not well suited for the supercomputer environment. The system weaknesses appear to be in its memory handling, I/O, algorithm and small mesh sizes for scalar processing computers. The overall purpose of this case study evaluation was to develop a comprehensive methodology for studying reliability of geotechnical systems, accounting for deformation in rock slopes. Results of this study will permit one to apply the vector algorithm methodology to specific geotechnical problems such as the footwall anchoring at Smoky River Coal Limited.

c) Seepage Analysis

This system was designed and developed by CANMET/EMR during the 1970s for a 36-bit machine. Many machine dependent features and memory management I/O are present. The essential structure of the program requires a complete rewrite to bring it in line with today's architecture. The finite element procedure also needs to be modified considerably to run on a vector machine (or replaced with a suitable library routine to make it more efficient). This program is by far the one most suitable for analysis on a vector machine because of its inherent complexity.

Initial investigation showed that satisfactory answers to our questions were possible. More detailed work was necessary because of the complexity of the algorithms and data requirements. Development or adoption of a two- or three- dimensional model to study flow through a fractured geological medium was an important area for further work.

Information on the geology, data from piezometers, slope geometry employed at the site, and excavation sequence followed were obtained from studies previously conducted at Pit No. 3, Highvale Mine, TransAlta Utilities and from the design and the footwall anchoring program at the Smoky River Coal Ltd. For purposes of this analysis, the test data supplied with the pit slope programs were used. The model was calibrated for further study with the help of data and test results acquired previously. The next step required will depend on the application to a specific site using design programs in a supercomputer environment.

d) PREDICT

The Institute of Sedimentary Petroleum Geology developed this computer-based system for quantifying surface-mineable coal resources according to environmental characteristics. The system was written in FORTRAN to run on Hewlett-Packard hardware. Although it has since been modified to run using FORTRAN 77, it has a built-in requirement for machine dependent features like sorts, a number of separate I/O operations, etc. This program does not lend itself to adaptation to a supercomputer environment without considerable reorganization. It is by far the most easily transportable system, but not much speed improvement can be expected.

e,f) INCOIL / CONCOIL

This program, cited in literature for use in oil sands applications, was obtained from the Civil Engineering Department, University of British Columbia. The work was sponsored by Alberta Oil Sands Technology and Research Authority (AOSTRA).

INCOIL, or "incremental dilatant elastic model of oil sands", calculates stresses, strains and displacements in soil elements, and internal forces and displacements in structural elements by means of analysis which simulates the actual sequence of construction operations. Approximately 4000 lines of source code was included in the tape.

CONCOILG is a sub-set of INCOIL. It is a mesh geometry program for nonlinear consolidation analysis of stress, deformation and flow in oil sand masses. (It has approximately 1350 lines of source code.)

CONCOILM belongs to the same group of programs received from UBC. This program is used for analysis of consolidation and gas exsolution in oil sands. (It has approximately 5500 lines of source code.)

These programs were written in 1984-1986. They were written in well structured FORTRAN for traditional scalar mainframes, using short vectors. They have limited capabilities and are not well suited for conversion to supercomputer technology.

8.3 The Benefits and Drawbacks of Vector Processing

The standard method of computing, called scalar processing (used in case study programs such as pit slope programs and PREDICT), processes data basically one step at a time. Vector computing, on the other hand, is the strategy employed on most supercomputers and essentially processes data in an assembly line fashion.

Vector processing is increasingly being used in industry to guide the direction of both product research and product development models. The benefits of vector processing for mining applications are

- High performance computing systems pay for themselves in complex simulation, reducing the cost of research, and reducing the time to bring a mine to production.
- Vector processing increases the power of design goals using the power of finite element analysis programs.
- Vector processing reduces drilling costs in exploration since geophysical modelling processes are cost effective in a vector processing environment.
- Highly vectorized simulation codes take full advantage of vector machines.

The benefits also extend to the operation side in a number of areas such as econometric modelling, material handling, maintenance planning and simulation of financial and investment models.

In order to take advantage of vector technology, it is not enough to simply substitute, on a one-for-one basis, vector statements for scalar statements in the user's program code. This approach, called local vectorization was the first step in our conversion efforts of the original pit slope programs. Experience indicates that these programs must be radically redesigned using current numerical algorithms to gain the benefits of the vector processing architecture of the machine.

For input-intensive applications such as the PREDICT, INCOIL and CONCOIL programs, data files have to be drastically restructured in order to take advantage of vector processors. Once again, this requires building the programs from the ground up with vector processing as a design criteria.

The process of vectorizing a major library of scalar applications such as the pit slope programs is not trivial. It will require a considerably long time to complete an entire project. Back in the 1960s, Gene Amdahl analyzed the performance of vector processing machines in terms of the degree of speed these systems provide over the that of standard scalar systems. For example,

vectorizing only 50% of a program's code will lead to a speed increase of only 1.9 times that of the original speed. In fact, the user has to get into the 80%-90% vectorization region before an appreciable percentage of the supercomputer's vector performance is achieved.

Questions often arise regarding the ability of various applications to be cast in vector form. However, the selected computing problems can be reformulated with different approaches, allowing the application of vector routines. We devised new approaches which were as best as could be expected under the restrictions mentioned above.

This being a preliminary study, a number of important conclusions for future reference follows.

8.4 Conclusion

In conclusion, some design considerations that impinge upon the effective use of a supercomputing environment for mining applications are discussed. Very specialized capabilities need to be provided so system users can gain full advantage of the immense processing power at the heart of the supercomputer. The implications of this case study directly suggest the human and physical resources required to answer the key questions posed earlier. In particular, the following factors require special attention and focus:

- User applications need to be converted to take full advantage of the vector processing power of the central processor. Vector algorithms are computationally quite different from the traditional scalar algorithms found in programs such as the pit slope programs. Typically, users require the help of specialists to modify the code.

- Utilities which provide file management, database, and input-output capabilities are usually not as highly evolved as those normally found on standard data processing systems. This limitation in our case was obvious from the start and hence only limited benchmarking was possible.

- High-speed input/output becomes critical when one notes the amount of data generated by mining applications on a supercomputer system. For an application such as PREDICT, modelling in computational geology can generate coordinates for every step in the calculation. This requires considerable storage.

- High-speed network access is important for remote users in mining sites who wish to pass large data files to the system and receive results back on an interactive basis. A number of attempts are now being made to provide centres with networks capable of high data rates.

- Workstations need to have the power to manipulate and display the large volumes of data that the supercomputer returns to the user. Machines serving this purpose are powerful computers in their own right. The more advanced engineering workstations typically run at 20 MIPS (million instructions per second) with large on-board memory arrays and sophisticated multi-tasking operating systems.

- High-performance graphic display and plotting devices are needed to compress the volume of results produced into a form amenable to interpretation and analysis by the user.

To prevent bottlenecks at any point in the process, high performance capabilities are essential, including the quick transfer of data between the user and the applications on the supercomputer.

The conclusion reached from the case study evaluation was that further work will be necessary in order to derive full benefit from supercomputing technology.

9.0 Discussion of Alternative Modelling Approaches

The late Dr. D.F. Coates pioneered the development of scalar coding for pit slope programs with the Pit Slope Manual in 1976. This brought about substantial benefits in mining efficiency through improved slope design. By modifying Coates' pit slope programs, a new line of vectorized and modularized libraries of surface mining geotechnical modelling applications will be created. Strong interest in the project has been expressed both in Canada and in other countries throughout our progress. This new line of models, in keeping with the original objectives of this project, will be developed in response to the mining industry's demands for ease of use and maintenance. With these models, during model construction the user can alternate between the slope stability and seepage analysis approach and sensitivity studies to quickly determine a sufficiently accurate method. In addition, rheological behavior can be modelled in either the finite element or coupled-finite element method with additional work. Very little additional input will be required from industry sources for this model.

Another important development in mine simulation is menu-driven microcomputer based data input and output processing software; this reduces the need for complex commands and gives the ability to quickly plot hardcopy of input and output data for checking or analysis. The mining engineer or consultant who has never had access to geotechnical engineering modelling technology before can now use this technique by

- Leasing or purchasing the workstation input/output data processing software for a PC
- Entering rock properties and hydrogeological data set following the menu-driven prompts displayed by the workstation pre-processing input software
- Transmitting the input data set to a supercomputer (either electronically via a modem or mechanically by sending a floppy disk or tape in the mail) to submit a run on the desired simulation or optimization model
- Downloading the simulation output data to a PC for display and analysis using the workstation output processing software
- Conferring with supercomputer modelling experts about unresolvable questions, procedures, or algorithms, including input data preparation, model selection, and consulting.

9.1 Supercomputer Model Development Environment

Preparation of geotechnical engineering model data has long been considered one of the most time-consuming and tedious phases of the mine modelling and simulation process. The advent of advanced computer hardware and software engineering practices for workstations and mainframes has dramatically reduced the time and manpower required for the data input phase of a simulation study. Constraints and upper/lower boundary range values for input parameters also reduce the risk of wasted runs. By minimizing the difference between measured and predicted behaviors, the model can be improved and made more easily accessible, fast and accurate. The workstation post-processor makes this possible.

9.2 Future Model Development

Modularized mine modelling and simulation packages coupled with a mine simulator workstation input/output data processor, make comparison of alternative design schemes a procedure much faster than previously thought possible. Many mine design and engineering management decisions can be improved through the use of supercomputer programs and simulation tools. These include

- Development of geological models
- Surface and borehole geophysics analysis
- Geotechnical engineering modelling applications
- Mine design, and sequencing for long and short term planning
- Production and/or Process planning
- Material handling and blending to meet market or mill constraints
- Environmental planning
- *in situ* mine modelling

10.0 Conclusions

Surface coal mining geotechnical modelling applications on a supercomputer is a complex task. After a careful study of available information and scalar models developed for traditional mainframes the following tentative future directions of this work are suggested:

1) Alternative modelling approaches based on advances in computer hardware and software technology will help give more economical, reliable and accessible facilities to the mining industry.

2) The development and/or acquisition of user-friendly software interfaces that prompt user actions in an almost expert-like manner are pushing state-of-the-art technology to the levels where it is needed most: the operating offices of mining companies of all sizes.

3) Effective mining simulation for geotechnical applications depends on the use of vector computers, but effective use of such computers requires careful attention to algorithms and reliable software techniques.

4) Conventional methods of evaluating programs and algorithms are frequently difficult when applied to code adopted to run on supercomputers. Issues related to software evaluation, and algorithms in use were examined and conclusions outlined in this report.

5) It is possible to develop a library of programs that operates efficiently on a supercomputer like the Cyber 205 system. It turns out that most parts of the code examined from pit slope program are adaptable to vectorization. In our preliminary work, in however a brief period of time, we achieved a twofold to threefold increase in model efficiency in scalar mode when compared to a model developed in mid-1970s. Further performance improvement is possible by doing additional work in line with the original objectives.

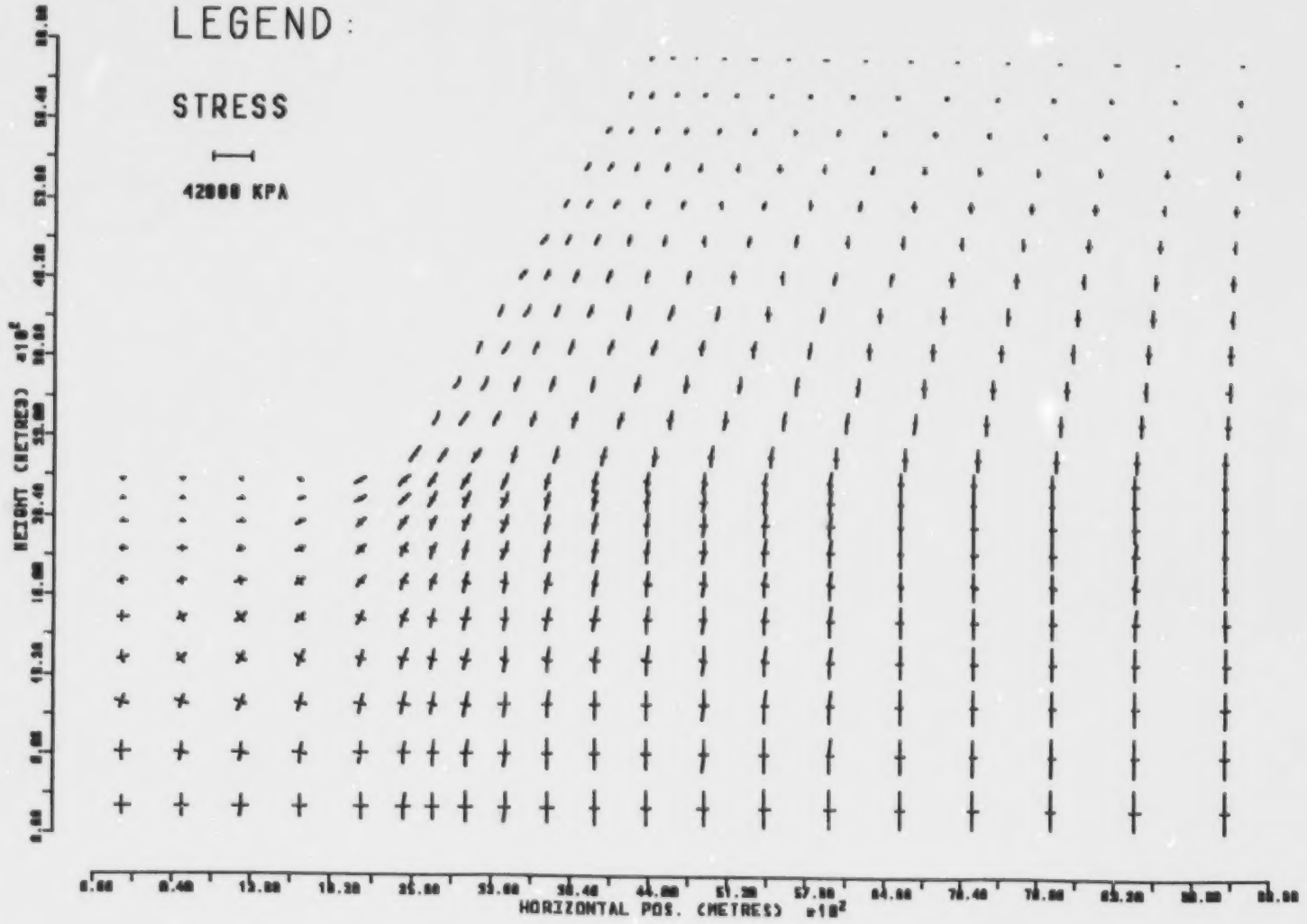
6) A consortium for reasearch in surface mine modelling proposal based on this project should invite participation from the coal and oil sands industry. The overall objective of the next phase of this project is to extend the processing capabilities to field problems and interpret and apply the results. Specific goals should include: i) enhanced reconstruction of numerical models for slope stability and ground water studies, ii) interpretation of field data using surface geophysics for mining applications, and iii) development of further physical and numerical modelling capability and analysis for large scale oil sands mining applications.

Overall, vector computing has increased the speed, accuracy and upper bound for simulation models using realistic field data for the test cases used. With supercomputers and highly vectorized code, it is possible to adequately demonstrate and model many of the conventional processes important to the mining industry. However, further efforts are needed to successfully model the more difficult field conditions where the geological or engineering complexities are beyond the scope of present-day models.

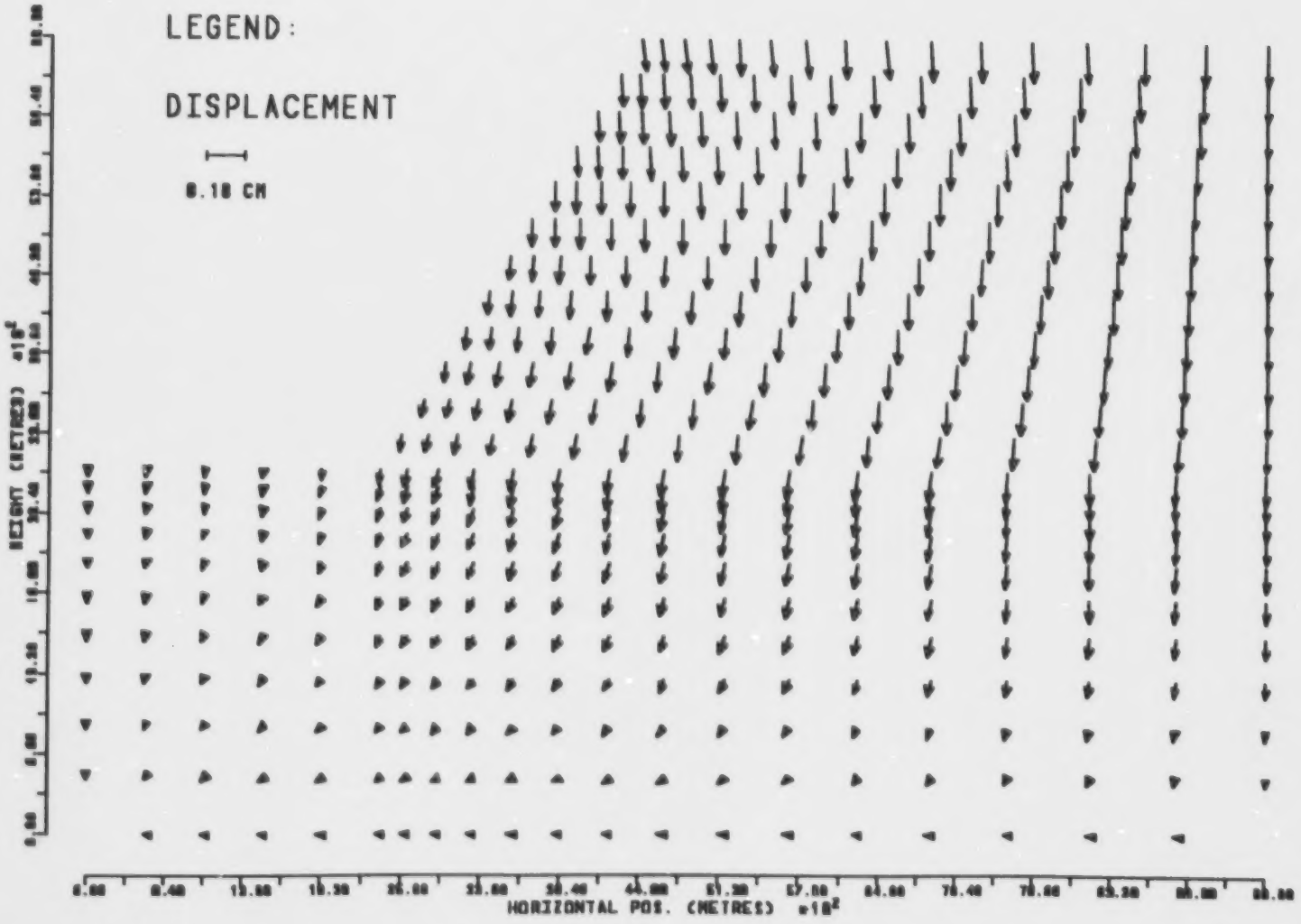
Appendices:

- Case Study Figures
- List of Contacts and Discussions Held
- Network of Research Centres
- Software Application Directory Questionnaire

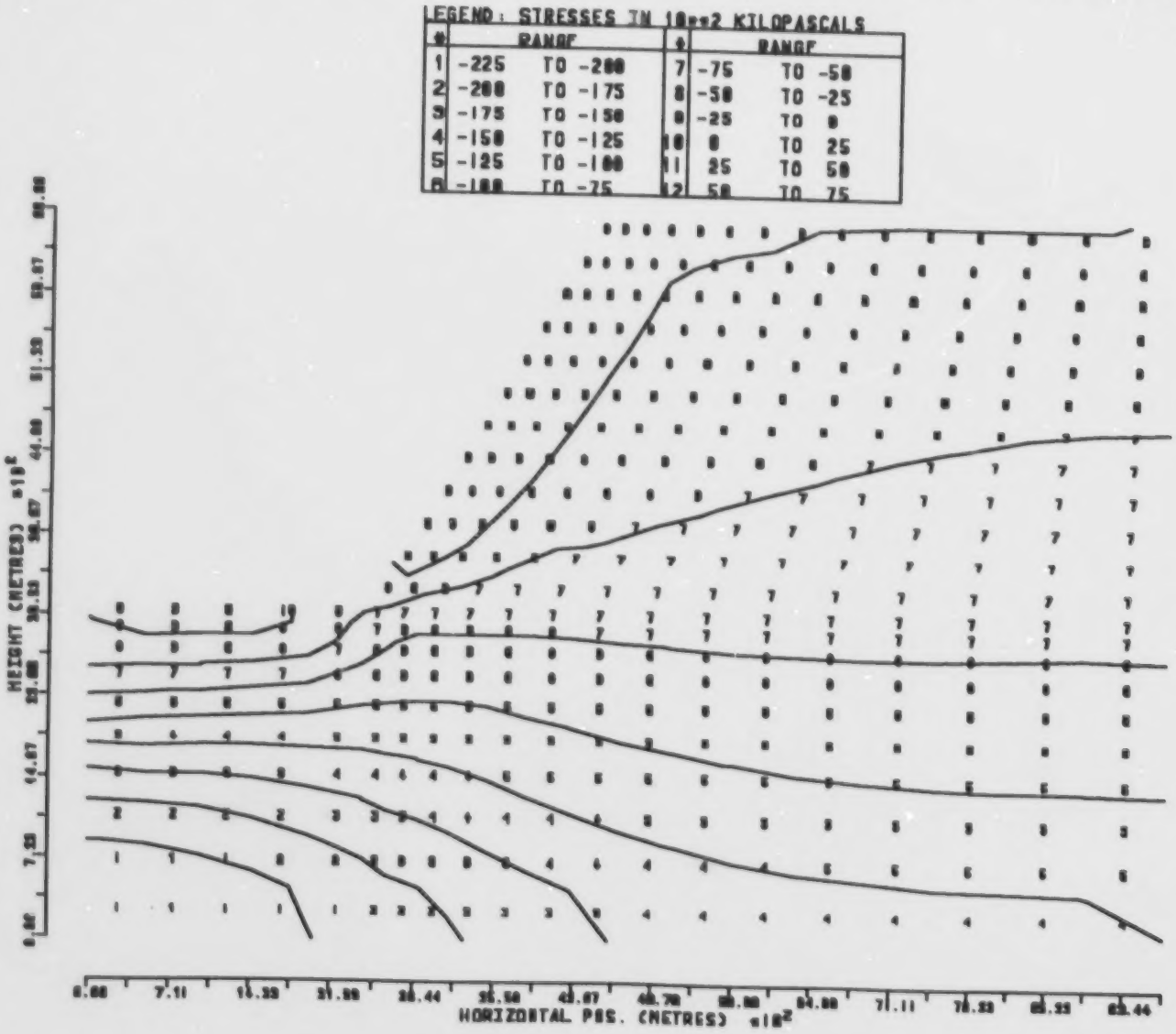
PRINCIPAL STRESSES PLOTTED AS VECTORS IN CRITICAL REGION



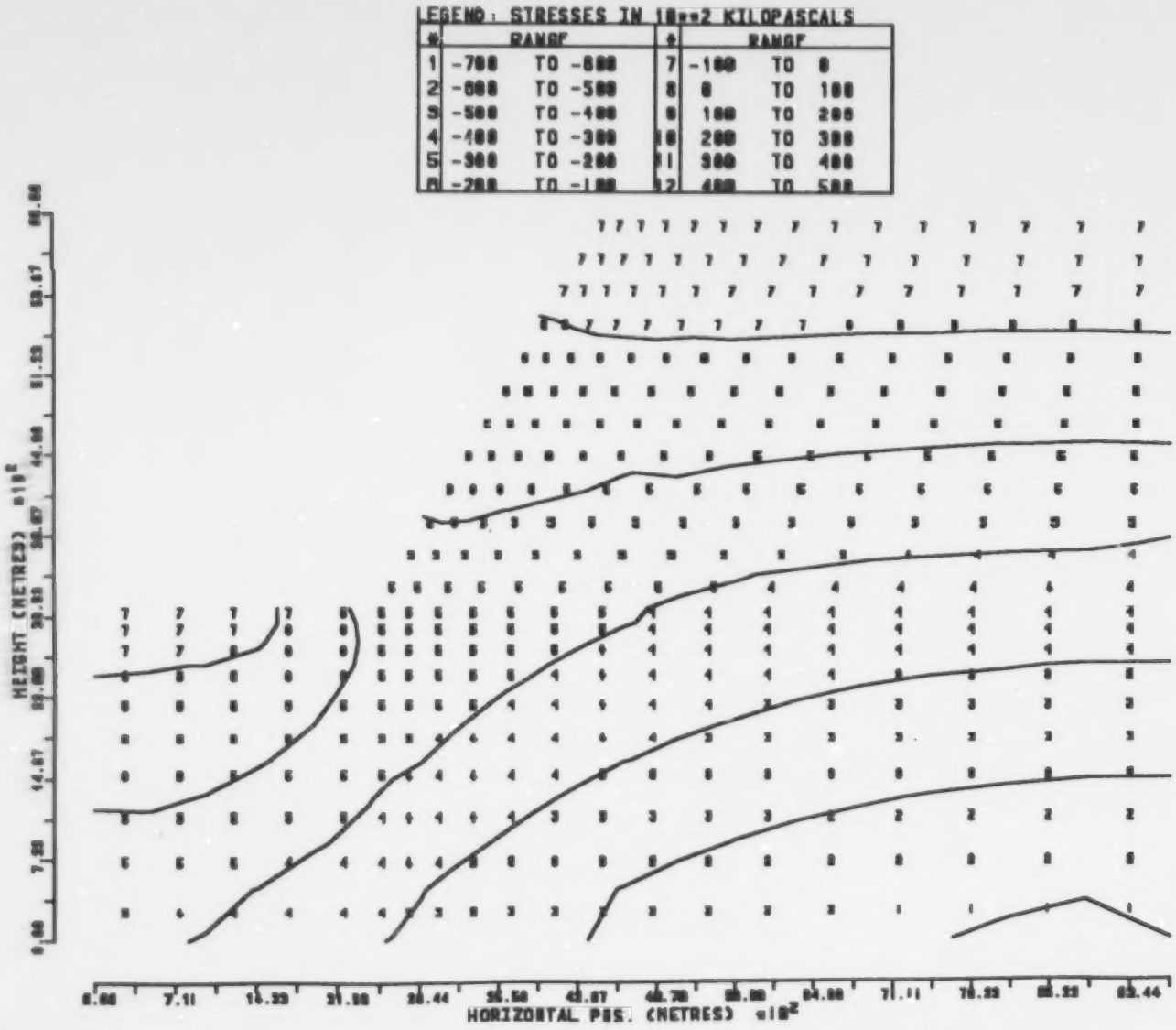
EXCAVATION DISPLACEMENT VECTOR IN CRITICAL REGION



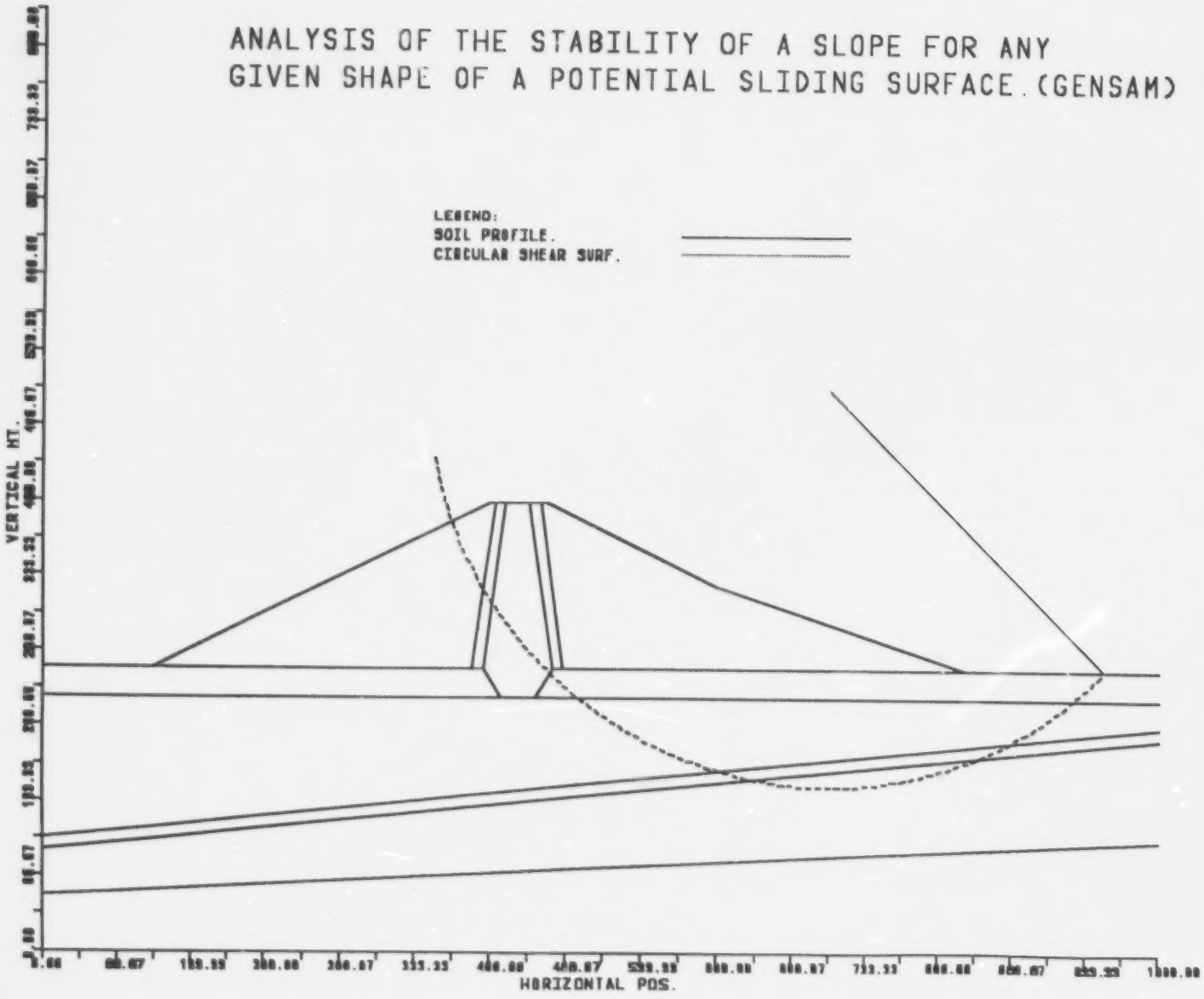
MAJOR PRINCIPAL STRESS POINT CONTOUR PLOT IN CRITICAL REGION



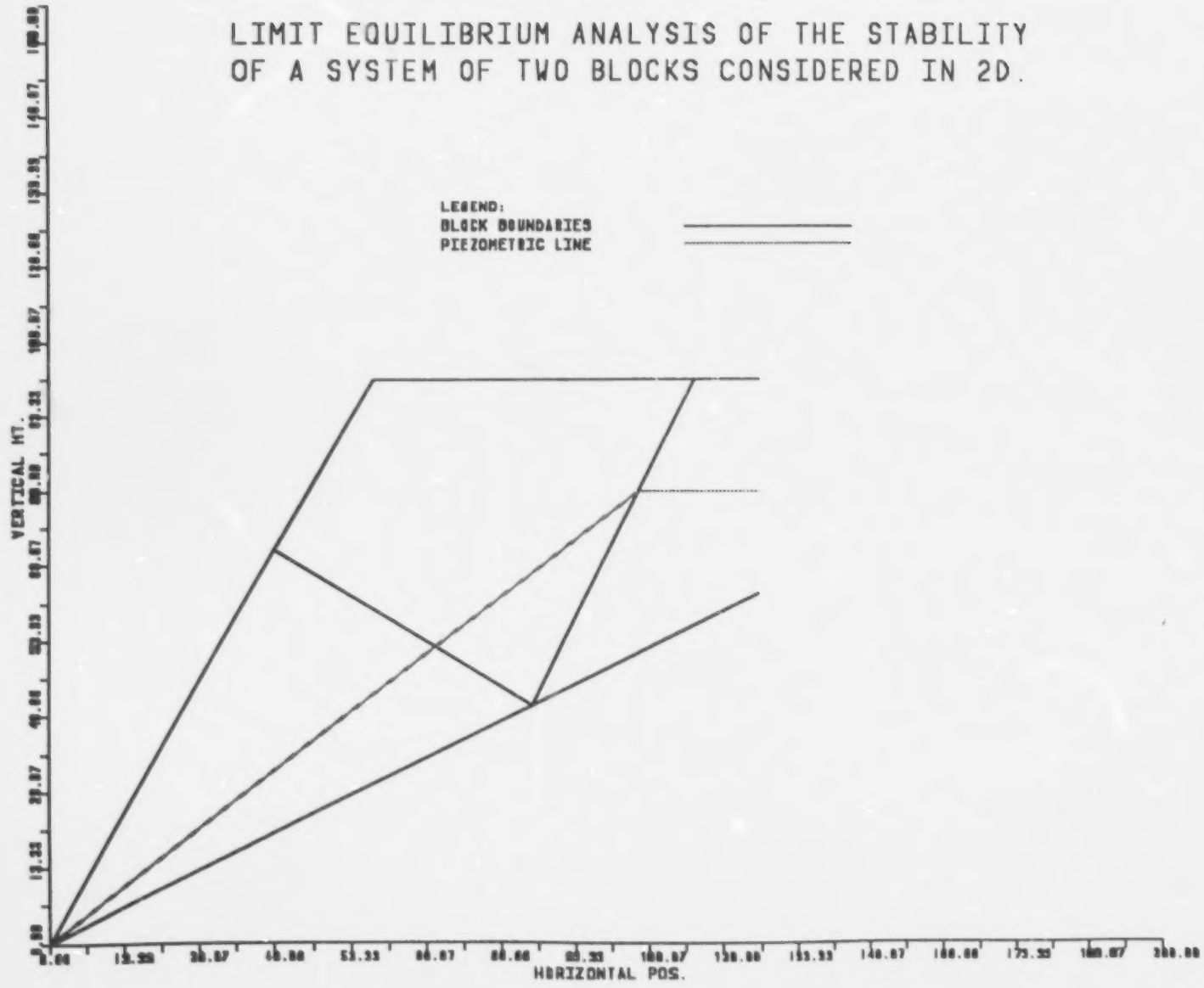
MINOR PRINCIPAL STRESS POINT CONTOUR PLOT IN CRITICAL REGION



ANALYSIS OF THE STABILITY OF A SLOPE FOR ANY
GIVEN SHAPE OF A POTENTIAL SLIDING SURFACE.(GENSAM)

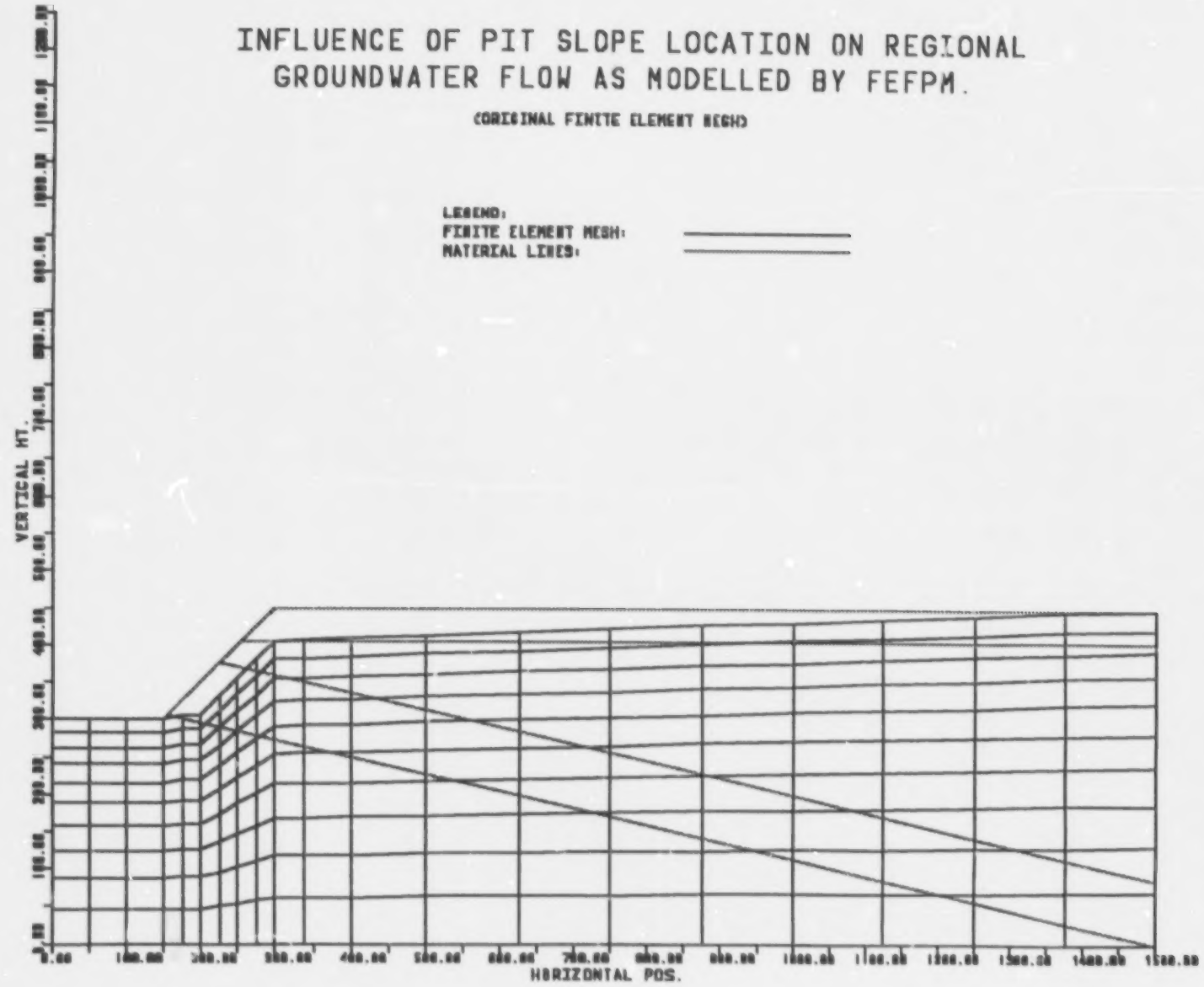


LIMIT EQUILIBRIUM ANALYSIS OF THE STABILITY
OF A SYSTEM OF TWO BLOCKS CONSIDERED IN 2D.



INFLUENCE OF PIT SLOPE LOCATION ON REGIONAL GROUNDWATER FLOW AS MODELLED BY FEFPM.

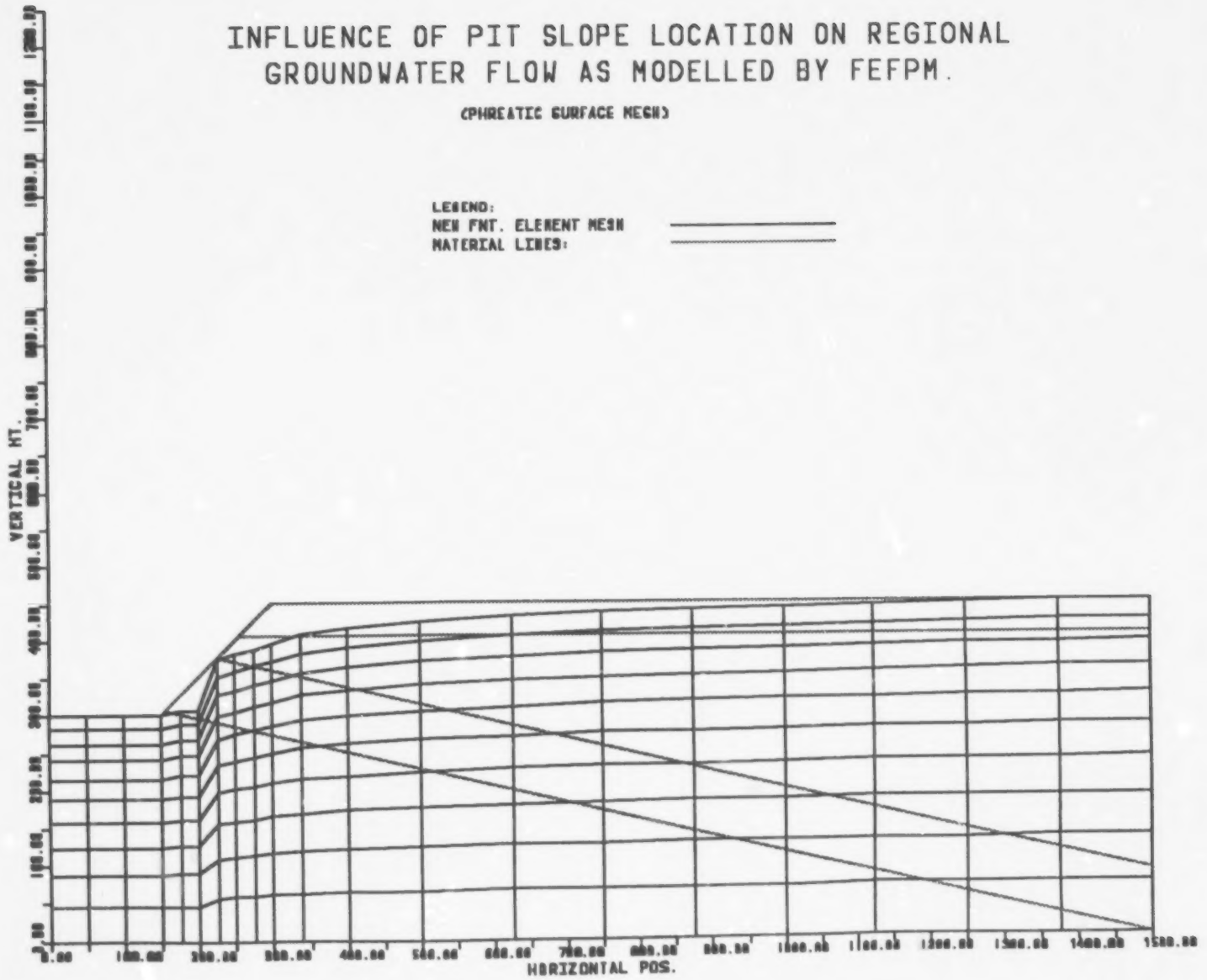
(ORIGINAL FINITE ELEMENT MESH)



INFLUENCE OF PIT SLOPE LOCATION ON REGIONAL GROUNDWATER FLOW AS MODELLED BY FEFPM.

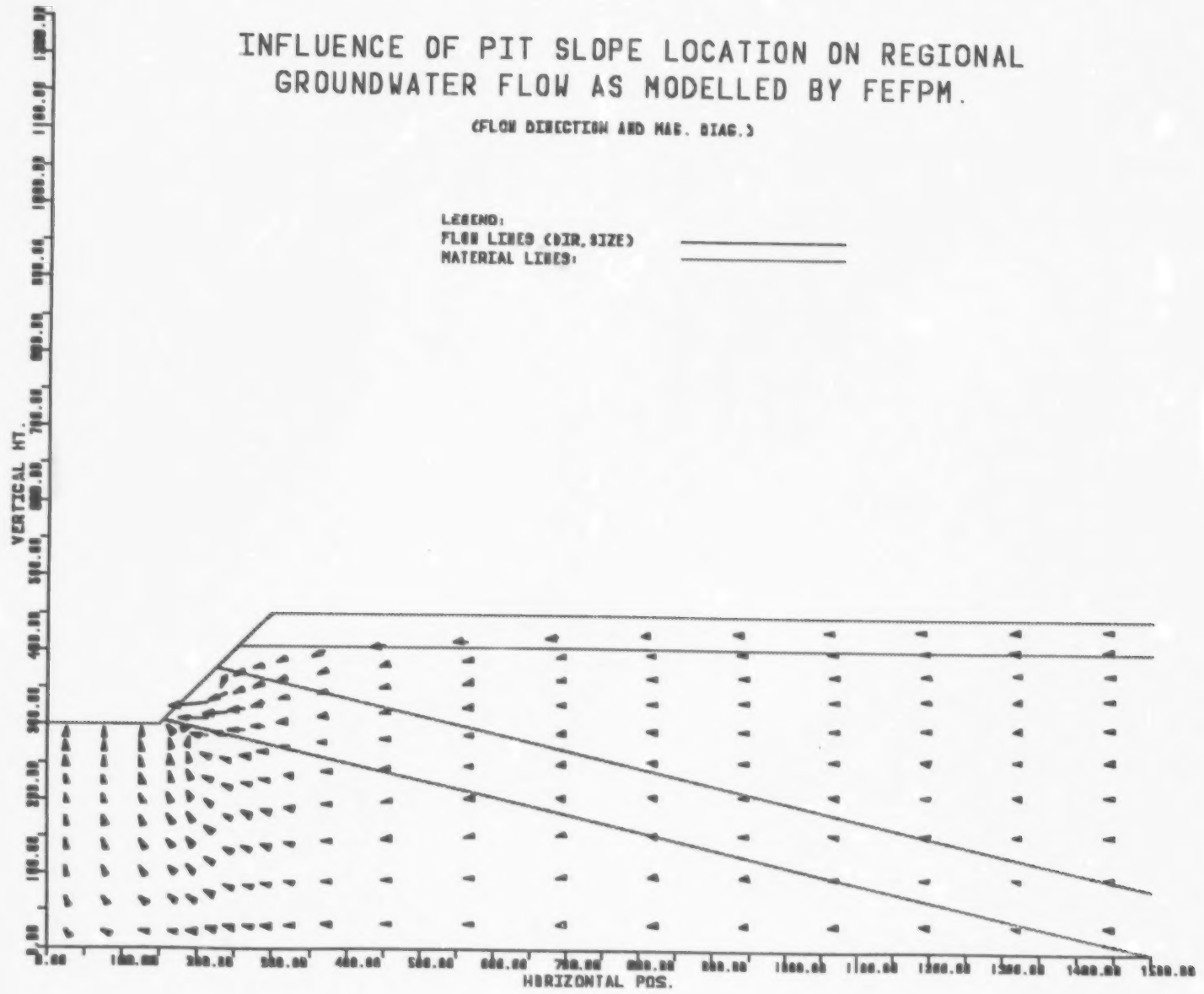
(PHREATIC SURFACE MESH)

LEGEND:
NEW FNT. ELEMENT MESH
MATERIAL LINES:



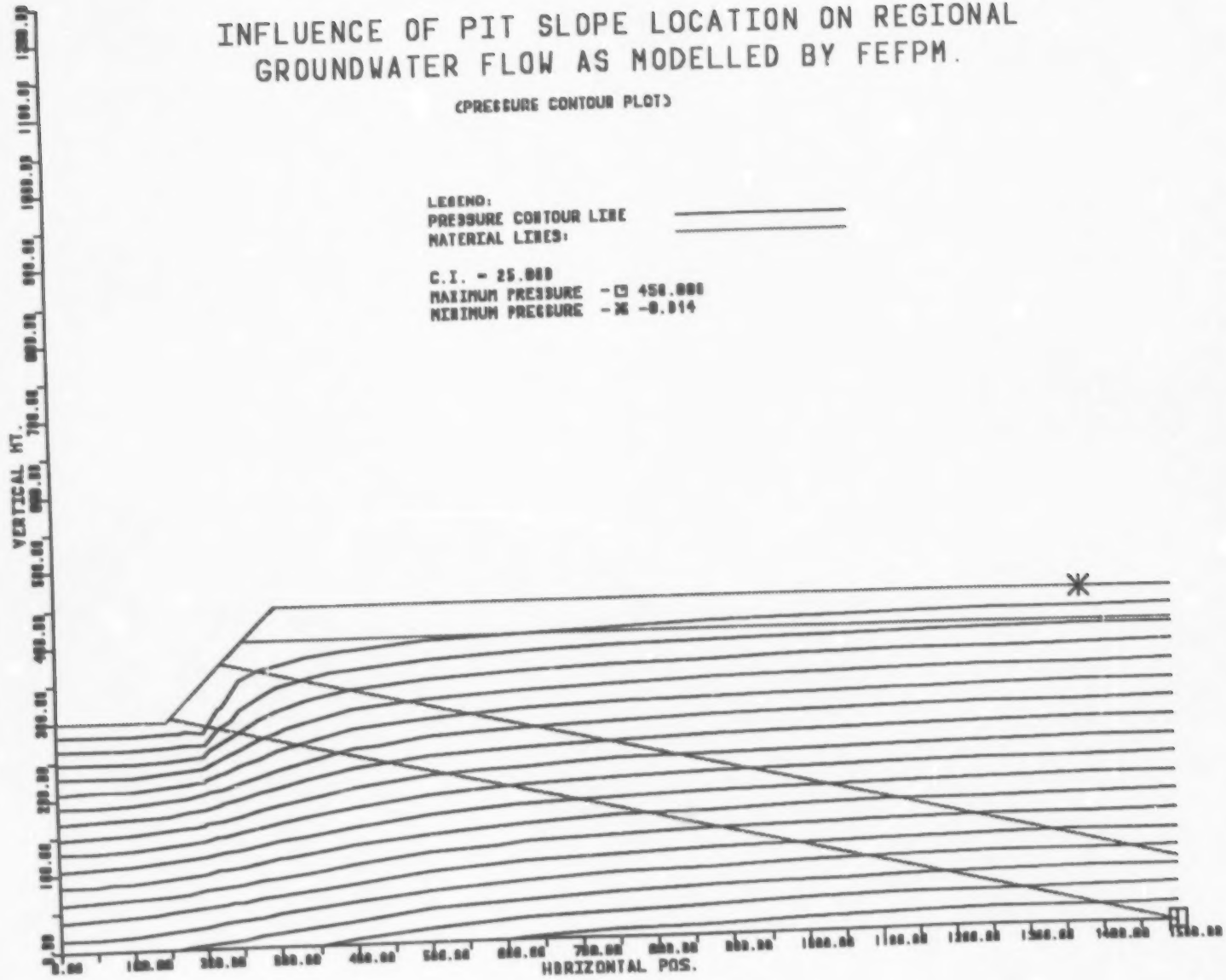
INFLUENCE OF PIT SLOPE LOCATION ON REGIONAL GROUNDWATER FLOW AS MODELLED BY FEFPM.

(FLOW DIRECTION AND MAG. DIAG.)



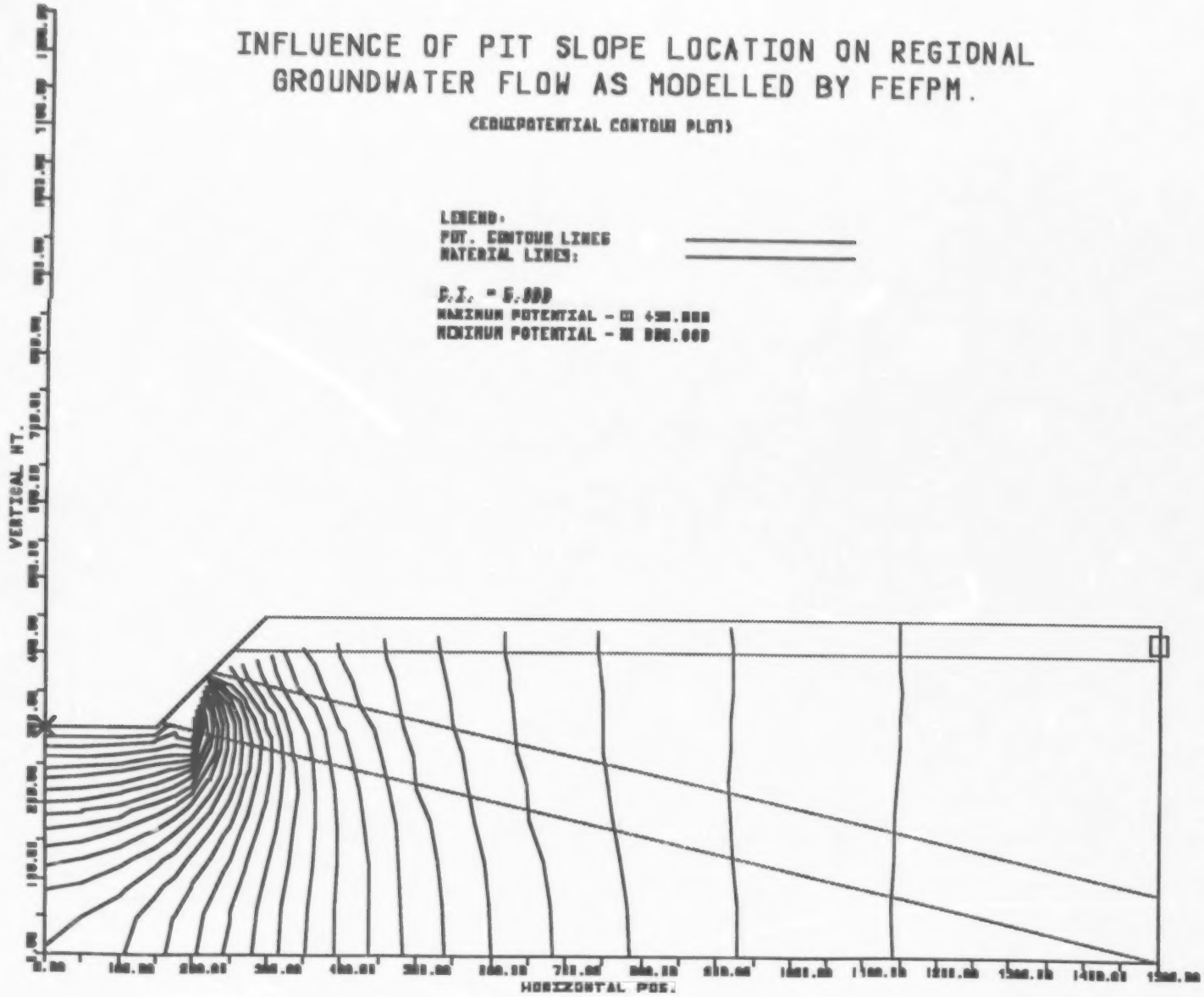
INFLUENCE OF PIT SLOPE LOCATION ON REGIONAL GROUNDWATER FLOW AS MODELLED BY FEFPM.

(PRESSURE CONTOUR PLOT)



INFLUENCE OF PIT SLOPE LOCATION ON REGIONAL GROUNDWATER FLOW AS MODELLED BY FEFPM.

(EQUIPOTENTIAL CONTOUR PLOT)

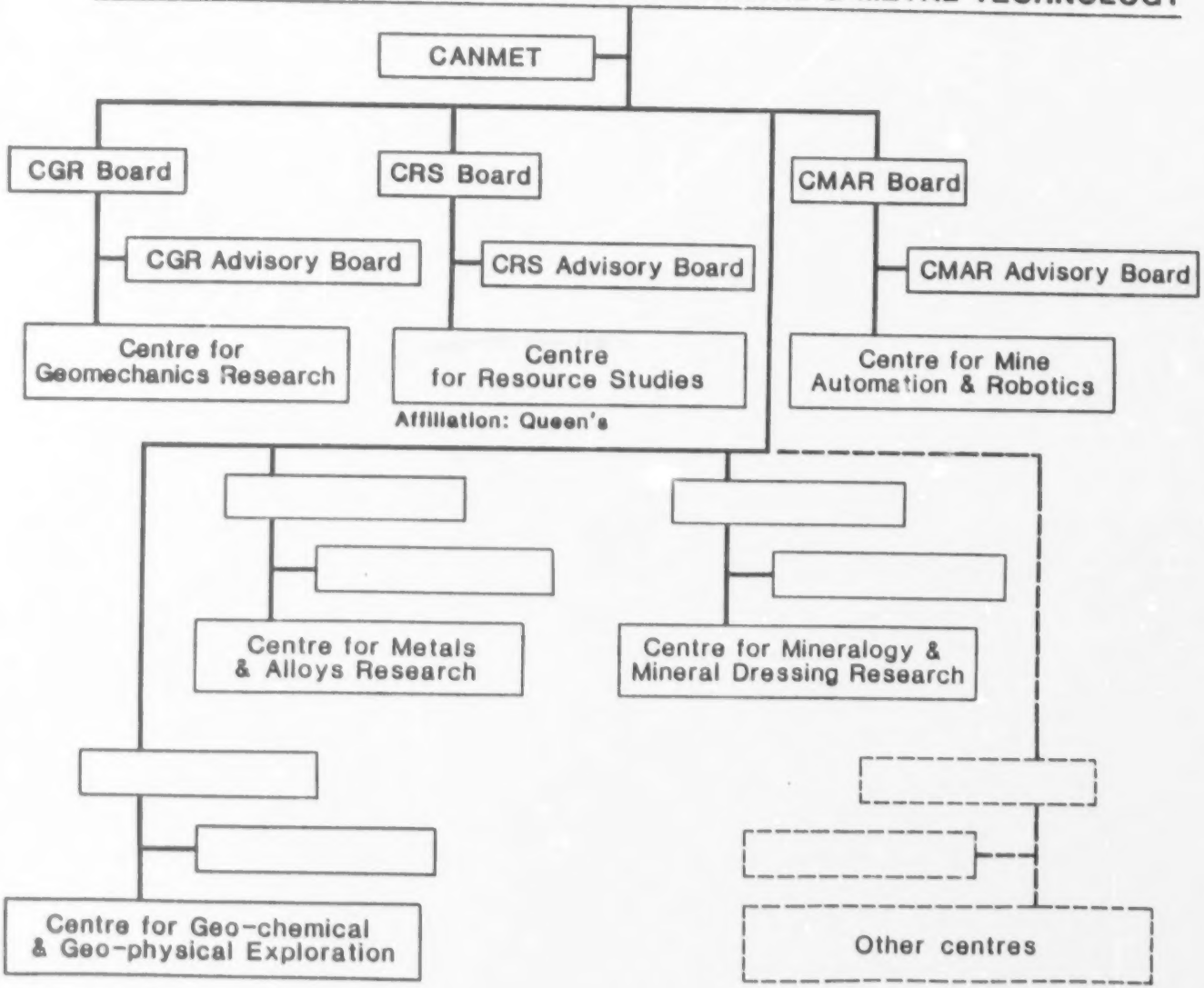


List of Contacts and Discussions Held

Organization/Individuals	*Subject*
TransAlta Utilities	
A. Hickinbotham	Highvale mine
Monenco	
Neil Wade	Slope stability
Tim Peterson	Groundwater
ERCB	
Ron Venter	Coal geology
Harry Antonio	
Brahm Prasad	Oil sands
Khalid Aziz	Coal statistics
ISPG(GSC)	
Dave Hughes	Coal Geology
Smoky River Coal	
Pete Sheehan	Slope stability
U.S.B.M	
- Denver	Mining Research
- Montana	Material Handling
- Pittsburgh	Coal combustion
Colorado School of Mines	Geosensing
U. of Alberta	
Dave Chan	SAFE program
U. of B.C.	
Dr. Peter Byrne	INCOIL program
CSIRO/Australia	
G.Beer	Pre- and post-processing
AOSTRA	
John Scott	
Neil Edmonds	Oil sands *in situ* mining

Occupational Health & Safety, Alberta	
Anant Prasad	Mine safety
Alberta Office of Coal Research & Technology	
Hari Sahay	Coal combustion studies. Areas of collaborative research with industry.
Canada Centre for Mineral and Energy Technology, EMR Mining Research Laboratories, Ottawa	
Dr. Y.S. Yu	Pit Slope programs and numerical algorithms for scalar and vector machines.
Dr. G. Herget	Rock Mechanics

CANADIAN INSTITUTE OF ADVANCED MINERAL & METAL TECHNOLOGY



Software Application Directory
Questionnaire - Mining

Application name:				
Application Type:		CAD/CAM		Mining
Other:		Modelling/Simulation		Graphics/Plotting
		Pre- / post- processors		Environment
Description:				
Operating System / Hardware required:				
Contact Name:				
Language Requirements:		**FORTRAN - 77**		C
Other:		**PASCAL**		
Requirements / Restrictions:				
Documentation:				
Support:				
Geographic Area Served:				
Installation:				
Education Use:				
Training:				

Glossary of Terms

Discretization	a procedure in which a complex problem (of large size) is divided (or discretized) into smaller equivalent units or components.
Finite difference method	a method used to discretize the basic governing equations of a model.
Finite element method	a method used to discretize a physical body or continuum.
Geomechanics	"the science that deals with the mechanical processes that take place in the earth's crust due to both natural factors and the influence of human activities."[26]
Geotechnical engineering	concerned with the behaviour of soil and rock masses in the vicinity of engineering structures.
Megaflop	Millions of Floating Point Operations per Second.
Numerical model	a procedure in which a complex problem is divided or discretized into smaller equivalent units or components.
Parallel processing	a machine in which a vector instruction is implemented by giving one pair of elements from the input vector to each of a huge number of processors, operating in parallel.
Pipeline	the mode of processing in which parallelism (see Parallel Processing above) is introduced by the overlapping of a linear sequence of operations for successive elements in the vector.
Scalar processing	traditional computers use a method of computation called scalar processing. In such machines there is a single stream of instruction which are interpreted and executed one at a time.

Supercomputer	the generally accepted definition of a supercomputer is a general purpose computer which is the most powerful computing engine available at any given time.
Vector	is a series of numbers stored one after the other in the computer.
Vector processing	simply refers to the capability of manipulating data in terms of vectors according to vector instructions
Virtual Memory	not true memory, but is a concept allowing users to address a very large fictitious memory called virtual address space.

References

1 Personal communication with Mr. C.G. Miller, President, Mining Association of Canada.

2 Energy Resources Conservation Board, Alberta, "Annual Coal Statistics", 1987, p.11.

3 ibid, p.9.

4 ibid, p.13.

5 ibid, p.35.

6 U.S. Congress, Office of Technology Assessment, Supercomputers: Government Plans and Policies, A Background Paper, March 1986, p.2.

7 MFLOPS is rate of execution, the number of million floating point operations completed per second.

8 Supercomputing Services, The University of Calgary, "Vector Programming in FORTRAN on the CYBER 205," May 1986, pp. 1-3.

9 ibid, pp. 1-4.

10 ibid, pp. 1-5.

11 ibid, pp. 1-6.

12 ibid, pp. 1-8.

13 ibid, pp. 1-10.

14 Mechanics of Geomaterials – Rocks, Concrete, Soils, ed. by Z.P. Bazant (John Wiley and Sons, 1985), p.528.

15 Numerical Methods in Geotechnical Engineering, ed. by C.S. Desai and J.T. Christian (New York: McGraw Hill, 1977), p.2.

16 ibid, p.3.

17 ibid, p.2.

18 ibid, p.2.

19 ibid, p.57.

20 Thomas Waldie (Syncrude) as quoted in interview with R.B. Hogarth, "Canadian Petroleum Association (CPA) Review", June 1987, p.3.

21 U.S. Congress, Office of Technology Assessment, Supercomputers: Government Plans and Policies, A Background Paper, March 1986, p.26.

22 ibid, p.26.

23 ibid, p.36.

24 ibid, p.36.

25 The term SPRD was coined by Serata Geomechanics, Inc., in "Model Development Report", prepared for CANMET, April 1987

26 Finite Elements in Geomechanics, ed. by G. Gudehaus, (London:Wiley, 1977), p.33.

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Desai, C.S. and Christian, J.T. eds., Numerical Methods in Geotechnical Engineering, New York: McGraw Hill, 1977.

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G. Gudehaus ed., Finite Elements in Geomechanics, London: Wiley, 1977.

Hanna, Thomas M., Field Instrumentation in Geotechnical Engineering, Trans. Tech. Publications, 1985.

Hogarth, R.B., "Canadian Petroleum Association (CPA) Review, June 1987.

Seminar/ Contract Debriefing, "Slope Stability Model Using SPRD Method at Highvale Mine", May 1987.

Serata Geomechanics, Inc., "Model Development Report" (prepared for CANMET/EMR), April 1987.

Supercomputing Services, The University of Calgary, "Vector Programming in FORTRAN on the CYBER 205", May 1986.

U.S. Congress, Office of Technology Assessment, Supercomputers: Government Plans & Policies, A Background Paper, March 1986.

Earth Resources/Mining Engineering:

Applications Software Directory

C. Janakiraman
Advanced Computing Technology Centre
University Of Calgary

GEOLOGY AND GEOPHYSICS

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
Bluepack - 3-D	Geostatistical Software handles all types of geophysical, drill hole data.	Stephen A. Krajewski Geomath, Inc. Lakewood, CO	FORTRAN
CPS-1	Plots contours from gridded or irregularly spaced data points.	Radian Corp. Austin, TX	FORTRAN
DATAMINE	Offers geologists and mining engineers a way to process their data.	Mineral Industries Computing Ltd. London, U.K.	FORTRAN
EAGLES	Engineering Analytic, Geologic and Land Management Evaluation System. A fully integrated resource evaluation system.	Morrison - Knudsen Corp. Boise, ID	FORTRAN
Geostat	Simulation of the variability, continuity and distribution of a variable - 5 programs.	Geostat Systems International Inc. 5180 Queen Mary Rd. Montreal, PQ	FORTRAN_77
GPCP/1	General Purpose Contouring Package. Automated contour mapping, plots seismic, and geological maps.	CalComp Anaheim, CA	FORTRAN
MEDSYSTEM	Mine Evaluation and Design System	Mintec, Inc. Tucson, AZ	FORTRAN_77
MINEPAK	Designed to do ore body analysis, mine planning, mine scheduling and financial analysis.	Earth Technology Corp. Golden, CO	FORTRAN

GEOLOGY AND GEOPHYSICS cont.

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
MINEX	Mine Evaluation and Simulation System. Designed for use by geologists, geophysicists, engineers and programmers.	Exploration Computer Services, Inc. Bowral, N.S.W. Australia	FORTRAN
MODELS	Provides modelling techniques for evaluating geologic and analytic data.	Morrison - Knudsen Corp. Boise, ID	FORTRAN
SGL	Surface Gridding Library	Dynamic Graphic, Inc. Berkeley, CA	FORTRAN
SURFACE II	Creates displays of spatially distributed data as contour maps or perspective and isometric block diagrams.	Kansas Geological Survey Computer Services Division Lawrence, KS	FORTRAN
SURPASS	Surface Mine Planning and Simulation System	Morrison - Knudsen Corp. Boise, ID	FORTRAN
TERRAPLOT	A complete contour mapping system.	TerraSciences, Inc. Lakewood, CO	FORTRAN

STRUCTURAL ANALYSIS - GEOMECHANICS

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
ABAQUS	Performs advanced structural and heat transfer analysis.	Hibbit, Karlsson and Sorensen, Inc. Providence, RI	FORTRAN
ADINA System	Effective finite element analysis of structural and field problems.	Klaus-Jurgen Bathe Adina Engineering, Inc. Watertown, MA	FORTRAN
BEASY	Boundary Element Analysis System. A general-purpose computer program.	Computational Mechanics, Inc. Billerica, MA	FORTRAN
BIEFE	Static, linear and stress analysis. Combination of finite elements and boundary element methods.	Dept. of Civil Eng. University of Queensland St. Lucia, Australia	FORTRAN
CANMET Pit Slope Manual	Stability, seepage, and rotational shear analysis programs.	Computer Services Centre Dept. of Energy, Mines and Resources Ottawa, ON	FORTRAN
CONCOIL	A computer program for Nonlinear Consolidation Analysis of Stress, Deformation and Flow in oil sands masses.	University of B.C. Vancouver, BC	FORTRAN
GEOMIN System	Generates finite element meshes and carries out analysis.	GEOMIN Vancouver, B.C. Denver, CO	FORTRAN
SAFE	Soil Analysis by Finite Element	University of Alberta Dept. of Civil Eng. Edmonton, AB	FORTRAN

STRUCTURAL ANALYSIS - GEOMECHANICS cont.

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
SLIDE	Slope Stability Analysis	RE/SPEC Ltd. Calgary, AB	FORTRAN
U.S.B.M.	Computer Program for Pit Slope Stability Analysis by the Finite Element Stress Analysis and Limiting Equilibrium Method	U.S. Dept. of Interior Denver Mining Research Centre Denver, CO	FORTRAN

MATERIAL HANDLING

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
ASPOL	General-purpose, process oriented simulation language for interacting processes.	ETA Systems, Inc. St. Paul, MN	FORTRAN
GPSS	General Purpose Simulator Software	Simulation Software Ltd. London, Ont.	FORTRAN
OPMHS	Open pit materials handling mine simulator.	Dept. of Minerals Engineering State College, PA Sponsored by USBM	FORTRAN
SIMSCRIPT - II.5	Discrete event simulation language.	CACI Inc. La Jolla, CA	FORTRAN
SLAM II	Advanced simulator language for modelling.	Pritsker & Assoc., Inc. West Lafayette, IN	FORTRAN

CAD/CAM/CAE

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
BELT	Used for analysing belt conveyer system.	FENCO Engineering, Inc. Toronto, Ont.	FORTRAN
CAE	Computer techniques for mine evaluation and design.	Wright Engineers, Ltd. Vancouver, B.C.	FORTRAN
DATAMINE	Suitable for modelling and interactive graphics.	Wright Engineers, Ltd. Vancouver, B.C.	———
Directional Drilling	Produces well plots in plan and elevation for all wells within a verticle slab.	Digital Enterprises Beverly Hills, CA	FORTRAN
DISSPLA	A unique programming/plotting tool for users.	CalComp Anaheim, CA	FORTRAN
FLUME	Used for analysing steep flumes subject to lateral flow.	FENCO Engineers, Inc. Toronto, Ont.	Binary
IBM (Interactive Surface Modelling)	Automated surface mapping.	Dynamic Graphics, Inc. Berkely, CA	FORTRAN
ICEM	(Integrated Computer-Aided Engineering and Manufacturing) set of programs for interactive graphics for CAD/CAM.	Control Data St. Paul, MN	———
MODL3-D	A system of user oriented modules to generate the mesh, plot the mesh, etc. for finite element code such as ANSYS, NASTRAN, ...	AECL Mississauga, Ont.	FORTRAN

CAD/CAM/CAE cont.

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
TERRAIN_ MODIFICATION	Used to create and to modify the shape of a surface and to graphically display and perform calculations.	Digital Enterprises Beverly Hills, CA	FORTRAN

GRAPHICS/IMAGE PROCESSING

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
DI_3000	An integrated system of graphics software tools. Device and machine independent.	Precision Visuals, Inc. Boulder, CO	FORTRAN
GIMAGE	Application package for black and white or colour image processing	Unitas, Inc. Dallas, TX	FORTRAN
IMAGE 3000	A library of subroutines associated with 2-D and 3-D image processing, manipulation and display	Adage, Inc. Billerica, MA	C and FORTRAN
MOVIE_BYU Version 5.4	A system of general purpose graphics programs that facilitates the display of 3-D, topological, and architectual models.	CAM Software, Inc. Provo, UT	FORTRAN
TEMPLATE	General purpose graphics software support system.	Megatek Corp. San Diego, CA	FORTRAN
TRACER	Ray tracing package that yields high quality graphics imagery.	Ray Tracing Corp. Pales Verdes Estates, CA	FORTRAN

ENVIRONMENTAL ENGINEERING

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
DEWATER	Calculates effects of dewatering for a system of pits or wells, and generates drawdown data resulting from dewatering.	In-situ, Inc. Laramie, WY	FORTRAN
FEFPM (Pit Slope Manual, CANMET/ EMR)	Arbitrary plane and axisymmetric flow in porous media.	CANMET, EMR Ottawa, ON	FORTRAN
PLFS	Probability of Low Factor of Safety computer program.	West Virginia University Morgantown, WV	FORTRAN, SPSS, SAS
RENAME	A computer program for stability analysis of slopes.	University of Kentucky Civil Engineering Dept. Lexington, KY	FORTRAN
SLA 3D	A 3-D, variability saturated groundwater contaminant transport model	Simons, Li & Assoc. Tempe, AZ	FORTRAN
SLOPE	Slope stability analysis system performs automated analysis of slope stability problems.	McDonnell Douglas Information Systems Group St. Louis, MO	FORTRAN
SWIFT	A 3-D, finite-difference groundwater model used to simulate flow and transport processed in geologic media.	Intera Environmental Consultants Austin, TX	FORTRAN

ENVIRONMENTAL ENGINEERING cont.

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
U.S.B.M. - RI7908/1974 U.S. Dept. of the Interior	Mathematical modelling of spontaneous combustion of coal.	U.S. Bureau of Mines Pittsburgh Research Centre Pittsburgh, PA	FORTRAN

GEOPHYSICS/MINING

Program Name	Brief Description	Contact/Developer	Computer/ Software Req'd
FKM - 200	Performs 2-D and 3-D migration	Petroleum Technology Center Control Data Corp. Houston, TX	FORTRAN
FORM3DA	A 3-D acoustic forward modelling program.	Petroleum Technology Center Control Data Corp. Houston, TX	FORTRAN